Trends and Fluctuations in Precipitation and Stream Runoff in the Queen Charlotte Islands

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FISH/FORESTRY INTERACTION PROGRAM

This study was undertaken as part of the Fish/Forestry Interaction Program, a multidisciplinary research study initiated in 1981. The program was started following a series of major winter storms in 1978 that triggered landslides over much of the Queen Charlotte Island forest land base. Originating on steep slopes, many slides deposited tonnes of debris in streams and on valley flats. The events raised private and public concerns over logging practices on the islands and prompted the establishment of the 5 year program. Overall objectives of FFIP were:

- to study the extent and severity of mass wasting and to assess its impacts on fish habitat and forest sites.
- to investigate the feasibility of rehabilitating stream and forest sites damaged by landslides.
- to assess alternative silvicultural treatments for maintaining and improving slope stability.
- to investigate the feasibility and success of using alternative logging methods, including skylines, helicopters, and by logging planning, to reduce logging-related failures.

The program is jointly funded by direct appropriations from the Canada Department of Fisheries and Oceans, the B.C. Ministry of Forests (Research Branch), and the B.C. Ministry of Environment (Fisheries Branch). Participating agencies include the Canadian Forestry Service (Pacific Forestry Centre) and the Forest Engineering Research Institute of Canada (FERIC), Vancouver, B.C.

Program results are published through the B.C. Ministry of Forests, Land Management Report Series as well as papers presented at symposiums, conferences and through technical journals.

For information about the program contact Ministry of Forests, Research Branch, 1450 Government Street, Victoria, B.C. V8W 3E7.

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ABSTRACT

A number of indicators of climatic trends in the Queen Charlotte Islands are examined in this report. The purpose of the analysis is to determine extent of climatic influence on recent increases in the incidence of slope failures and stream channel enlargement. Winter (October to April) total rainfall, precipitation, and snowfall; winter mean temperature; water-year (October to September) total stream runoff; and the exceedance of daily precipitation amounts were studied using a variety of trend and data homogeneity analysis techniques.

Although there was considerable lack of homogeneity found in the various long-term data sets available from the Queen Charlotte Islands, and a low regional coherence between the data sets, several consistent climatic fluctuations were evident. The most notable are the periods of generally above-average winter rainfall and temperatures, 1923 to 1946, 1957 to 1964, and 1974 to 1984, with intervening periods of generally below-average winter rainfall and temperature, from 1946 to 1957 and 1964 to 1974. The most recent of these fluctuations (since 1946) appear to correspond with general changes in synoptic-scale circulation patterns across the northeastern Pacific Ocean area. The period since 1974, particularly significant to the Fish/Forestry Interaction Program, includes 7 years of exceptionally high precipitation in at least some portion of the Queen Charlotte Islands.

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1 INTRODUCTION

This study was undertaken as part of the Fish/Forestry Interaction Program (FFIP), initiated in 1981 to evaluate the inter-relationships among logging practices, slope failure occurrences, and consequent stream impacts in the Queen Charlotte Islands. In investigations of the impacts on natural systems of land use changes such as logging, two questions should be posed about the condition of the natural systems:

1. Can any background events or rates of change that could affect the outcome of the land use change be identified in the natural system?

2. If background rates of change are present in the natural systems, to what degree could these be altered by the land use change?

This report describes the results of a study of background climatic and hydrologic trends in the Queen Charlotte Islands, dealing specifically with autumn/winter precipitation, frequency of intense precipitation, and annual stream runoff.

The findings of recent related investigations support this work on the Queen Charlotte Islands. Several studies on Vancouver Island have suggested that an increase in autumn/winter precipitation from the late 1940's to the mid-1970's has been paralleled by increases in channel widths in both unlogged and logged watersheds (Rollerson 1983; Karanka;[1] Karanka and Rollerson[2]). The rates of change in channel width were higher in the logged watersheds, reflecting a combination of effects from rate of cut, logging practices adjacent to channels, and increased sediment supply from bank erosion and slope failures.

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[1]Karanka, E.J. 1983. A review of changes in stream channel morphology in coastal British Columbia as related to flood-plain logging. B.C. Min. Environ., Water Manage. Branch, Victoria, B.C. Unpubl. working report.

[2]Karanka, E.J. and T.P. Rollerson. 1984. Changes in stream channel morphology on central Vancouver Island, British Columbia, in relation to climate trends and logging. Paper presented at Annual Meeting, Can. Assoc. Geographers, Malaspina College, 22-25 May, 1984, Nanaimo, B.C.

Church and Miles (1986) investigated the connection between a recent increase in the frequency of slope failures on the Lower Mainland of British Columbia and trends in annual precipitation and annual maximum 1-day precipitation. They concluded that the recent increase in slope failure occurrences coincided with a period of substantially higher than average annual precipitation and annual maximum 1-day precipitation.

Similar studies have been undertaken in Oregon (Lyons and Beschta 1983), northern California (Kelsey 1980; Lisle 1981), and New Zealand (Beschta 1983a; 1983b) -- all mountainous areas with slope failure problems and biogeoclimatic similarities to the Queen Charlotte Islands.

The objectives of this study were:

- to determine background trends in autumn/winter precipitation, frequency of heavy 1-day precipitation, and annual total stream discharge in the Queen Charlotte Islands; and
- to determine the synoptic context of any such trends.

1.1 Study Area

The Queen Charlotte Islands are located approximately 75-125 km off the northern British Columbia coast and extend about 275 km between latitudes 52° and 54°N (Figure 1). The island chain is comprised of three physiographic zones: the Queen Charlotte Range, the Skidegate Plateau, and the Hecate Lowland (Holland 1964). The Queen Charlotte Range, on the west coast of the Islands, is composed primarily of Triassic and early Jurassic volcanics, interspersed with several Jurassic granitic batholiths, particularly on Moresby Island. Heavily glaciated by local icecaps during the Pleistocene Epoch, the Queen Charlotte Range is indented by fjords. It is generally less than 25 km wide, with a maximum relief of about 1250 m. Very steep slopes are common, increasing the potential for slope failure.

The Skidegate Plateau, flanking the Queen Charlotte Range to the northeast, is comprised of generally flat- or round-topped ridges underlain by early Jurassic volcanics dipping to the northeast. Elevations range

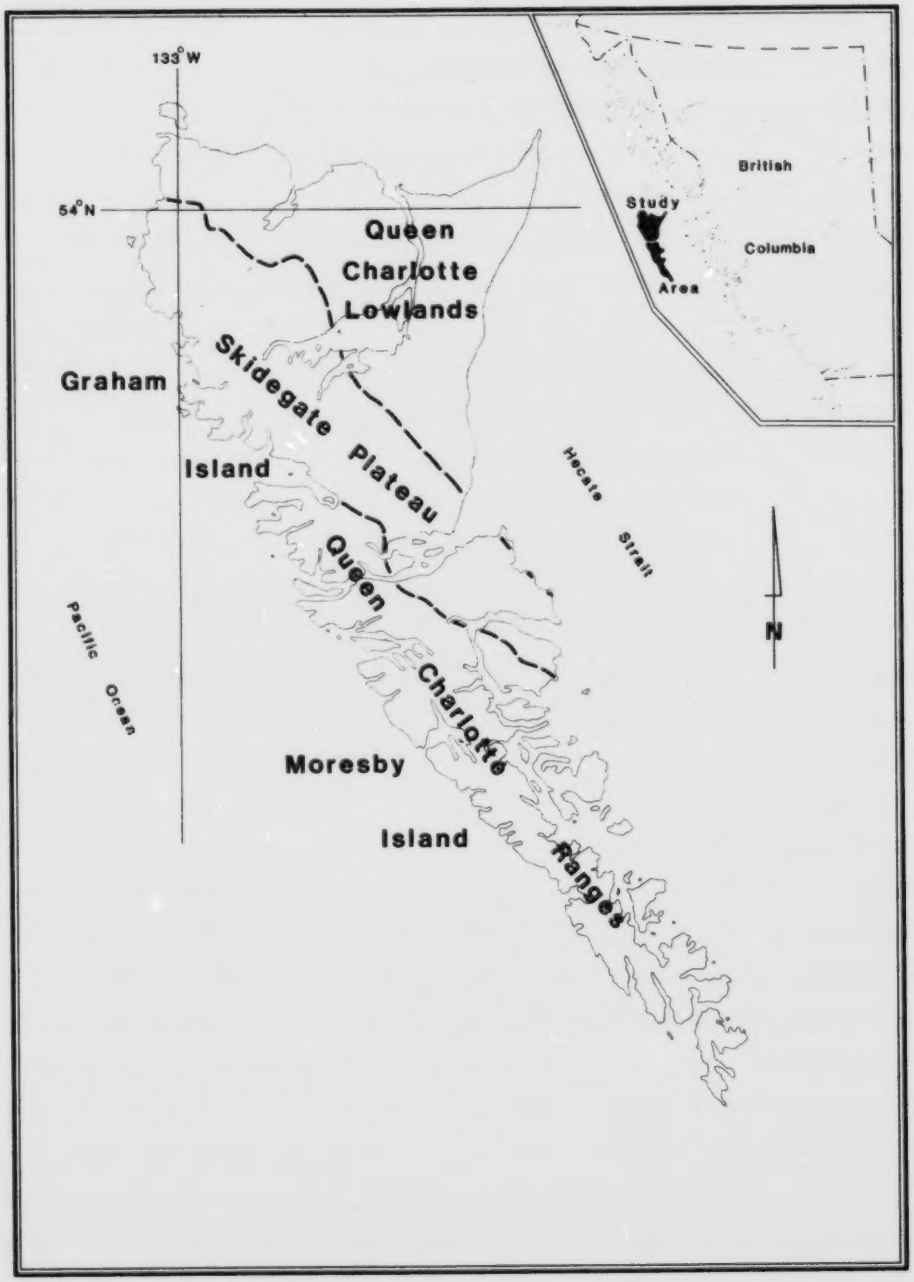

FIGURE 1. Major physiographic regions of the Queen Charlotte Islands.

from 300 to 600 m over a width of 20-25 km. The Plateau zone is present on the central and northern sections of the Queen Charlotte Islands. The Skidegate Plateau gradually becomes the Hecate Lowland to the northeast. This lowland is a 10- to 40-km wide coastal plain, underlain by Tertiary sedimentary rocks topped by Quaternary glacial sediments. The elevation is generally less than 150 m.

The Queen Charlotte Islands have a temperate coastal maritime climate, with a moderately seasonal distribution of precipitation. Mean monthly temperatures range from 1.2-3.6°C in January to 13.2-14.5°C in July at stations near sea level. About 70-80% of the precipitation occurs in the autumn/winter months of October to April. Most of the high daily precipitation events occur during this period, particularly in October and November. Mean winter snowfall on the coastal lowland varies from 60 to 80 cm, but snowpacks rarely persist for more than a few weeks. The winter snowline generally occurs at about 500-700 m.

Precipitation gradients are highly influenced by orographic uplifting across the Queen Charlotte Range. Mean annual precipitation increases to 4500 mm within 20 km of the windward outer coast, diminishing gradually across the leeward slope of the Skidegate Plateau. The low-lying, leeward coastal plain has a fairly low precipitation gradient, with annual means varying from 1200 mm along the coast to 1500 mm near the boundary with the Skidegate Plateau.

Changes in maximum rainfall intensities parallel the changes in mean annual precipitation across the Queen Charlotte Islands. One-day rainfall with a 5-year return period increases to 180-200 mm within 20 km of the outer coast, then declines gradually to about 50 mm along the leeward inner coast facing Hecate Strait.

2 METHODS

For analyzing climate trends, The World Meteorological Organization (WMO) recommends the use of the longest available homogeneous records, suggesting a 30-year minimum length of record. Only six records meet the minimum length criterion on the Queen Charlotte Islands (Table 1). Moreover, the distribution of the long-term stations is peripheral, with all located on the exposed extremities of the Islands or the eastern fringe of the coastal lowland (Figure 2). There are no long-term stations in the mountainous high precipitation zone which is the focus of the Fish/Forestry Interaction Program.

Thus, to maximize the data available for analysis, two other climate station records and the hydrometric record from the Yakoun River gauging station were used. All three have records between 19 and 25 years in length. Only the station at Tasu Sound, and to a lesser degree the Yakoun River hydrometric station, are representative of the high precipitation zone of the Queen Charlotte Islands.

Hydrometric records from Prince of Wales and Revillagigedo islands in the southern Alaska Panhandle were also analyzed, representing the longest coastal hydrometric data series north of central Vancouver Island. (All of the active north coastal British Columbia hydrometric records are less than 30 years in length.) The southern Alaska stations are approximately 160 km north of the north coast of the Queen Charlotte Islands, and 220 km away from the Yakoun River gauging station.

Other precipitation data series from northern Vancouver Island, central and north coastal British Columbia, and the Alaska Panhandle were also consulted -- as were winter temperature and snowfall records from the Queen Charlotte Islands climate stations -- to aid synoptic interpretation of the Queen Charlotte Islands trends.

The autumn/winter period (October to April) was used as the base period for analysis of precipitation trends, while the water year (October to September) was selected for analysis of total discharge volume at the hydrometric stations. These seasonal base periods were selected in preference to the calendar year so that the integrity of each annual maximal precipitation period, which begins in the fall and ends in the spring, could be maintained.

TABLE 1a. Summary of long-term Queen Charlotte Islands meteorological station data and history

Station	Years with records	Total years of record	Mean Oct. to Apr. ppt.	Mean Oct. to Apr. rain	Mean Oct. to Apr. snow	Mean Dec. to Mar. temp.
Cape St. James	1925-1940; 1944-	54	1117 mm	1082 mm	35 cm	
Dead Tree Point	1939-1958	19	884	809	75	
Langara	1936-	48	1219	1136	83	3.5 C
Masset (combined)	1897-1951; 1952-1968; 1971-	82	1023	948	75	3.0
Queen Charlotte City	1914-1939; 1940-1948	33	1397			
Sandspit Airport	1945-1946; 1948-	37	1013	933	80	
Tasu Sound	1963-	21	3287	3211	76	
Tlell	1950-	34	841	782	59	

Source: Atmospheric Environment Service Climate Normals 1951-1980

TABLE 1b. Summary of long-term Queen Charlotte Islands and southern Alaska Panhandle hydrometric station data and history

Station	Years with records	Total years of records	Mean annual water equivalent runoff (mm/unit area)
Fish Crk. (Revillagigedo I.)	1916-1935; 1939-	65	4524
Mahoney Crk. (Revillagigedo I.)	1921-1925; 1926-1933; 1948-1957; 1978-1981.	26	6343
Manzanita Crk. (Revillagigedo I.)	1928-1937; 1948-1967.	30	4843
Old Tom Crk. (Prince of Wales I.)	1950-	34	2270
Winstanley Crk. (Revillagigedo I.)	1937-1938; 1948-1975.	30	3535
Yakoun River (Graham I.)	1962-	21	2061

Sources: United States Geological Survey Anchorage Office

Water Survey of Canada Historical Streamflow Summary and Annual Surface Water Data

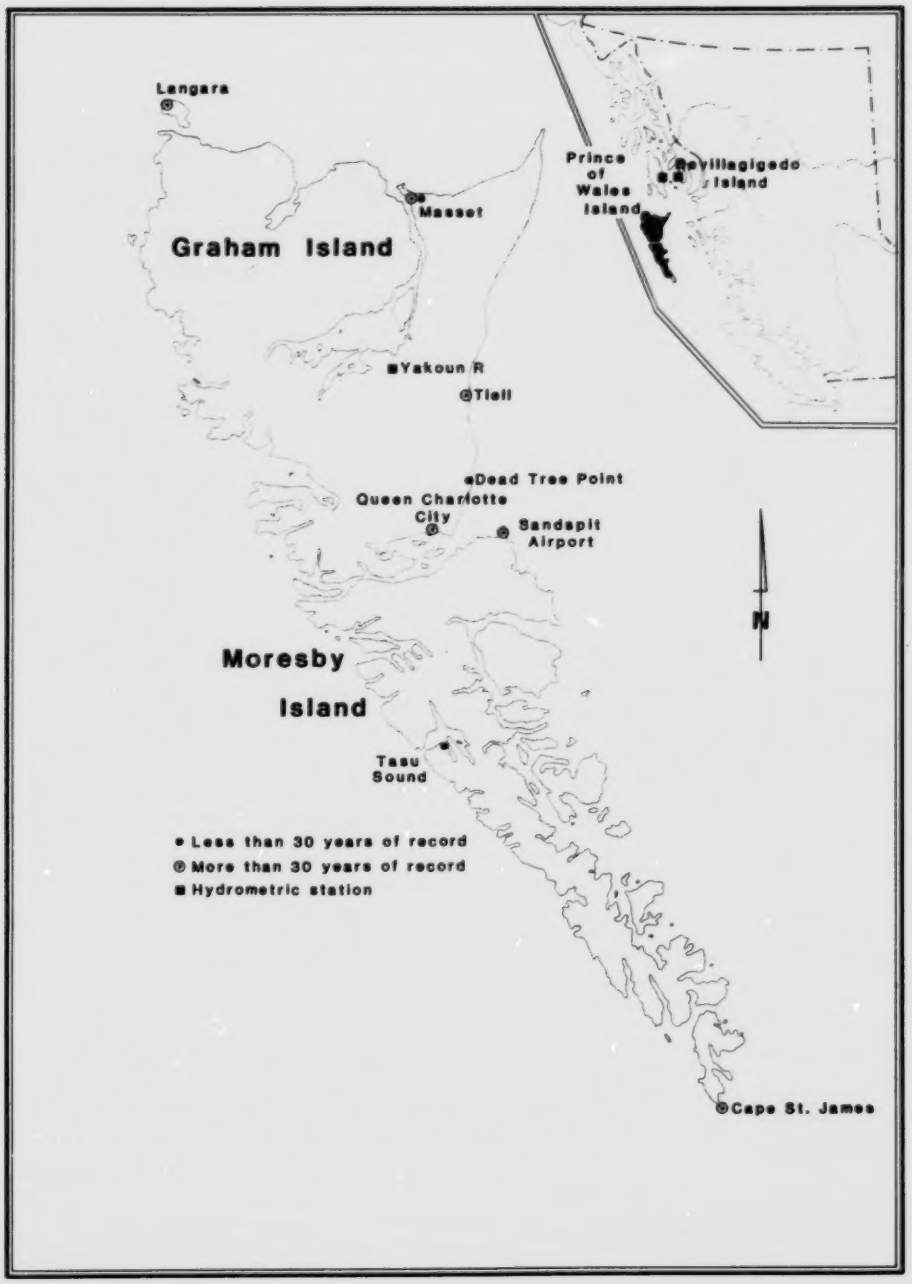

FIGURE 2. Location of stations used for Queen Charlotte Islands precipitation and runoff indices.

The hydroclimatic variables analyzed for trend in this study were:

1. October to April total precipitation.
2. October to April total rainfall.
3. October to April snowfall.
4. Water-year (October to September) total runoff volume.
5. October to April frequencies of 1-day precipitation greater than 30 and 50 mm, respectively.

The winter (December to March) mean temperature series from three stations were used for synoptic analysis.

Data analysis was aimed at determining: the homogeneity of data at each station, the coherence of regional data, trends in precipitation and stream runoff, and the synoptic context of any trends found.

The methods of analysis were generally the same for all variables except 1-day precipitation amounts and frequencies, which required a different approach. A specific sequence of analyses was developed for evaluating the data base, beginning with analyses of individual data series and leading up to regional data matrices. Tables 2 and 3 outline the sequences and summarize the rationale for each step. The entire sequence was not done for all variables, notably October to April snowfall and October to April rainfall. These two variables are subsets of October to April precipitation, and were covered by the sequence done for the precipitation data. However, snowfall and rainfall data were analyzed for specific interpretive purposes, to help clarify some features of the total precipitation data series.

2.1 Data Homogeneity Analysis

A key condition for analysis of climate trends from individual station records is the homogeneity of the data by station location, exposure, and instrumentation during the period of record. If the data are not homogeneous, at-a-station trend analysis may show spurious trends and may mask or distort genuine trends. Evaluation of data homogeneity involves three types of analysis:

TABLE 2. Sequence of analysis for individual station data series

Procedure	Rationale
1. Station history analysis	- identify potential long-term and supplementary records - provide an initial screening of data series for homogeneity problems Source documents: Canada Atmospheric Environment Service (AES) station catalogue; annual lists of station operators and postal addresses; station inspection reports.
2. Compile October to April precipitation, rainfall, and snowfall series. Compile December to March mean temperature series. Compile water year runoff series.	- unify the data series for each autumn/winter period (as opposed to splitting each maximal precipitation period when calendar year is used) Source documents: Printouts of monthly precipitation, rainfall, and temperature. Air Studies Branch to 1976. Climate of B.C. Air Studies Branch, 1977 to 1982 (Microfiche). Monthly climate summaries. Canada AES, post-1982 (Microfiche). Historical Streamflow Summary, British Columbia to 1982. Water Survey of Canada, 1983. Surface Water Data. British Columbia 1983. Water Survey of Canada 1984. Alaska Water Data to 1982/83. Water year compiled by United States Geological Survey Anchorage Office. Daily precipitation amount/frequency data supplied by the Canadian Climate Centre.
3. Compute mean and standard deviation	- these parameters are used in all subsequent analyses - log normal distribution was used for water-year runoff
4. Compute residual mass curve series (cumulative percent deviation series)	- carry out first statistical analysis and test of data series homogeneity or trend

TABLE 3. Sequence of analysis for regional data

Procedure	Rationale
1. Compute interstation correlation matrix	- indicate the degree of regional coherence between data series - can also indicate data homogeneity changes at individual stations
2. Compute double mass curve residuals	- identify data homogeneity changes at specific stations
3. Identify homogeneous data series	- eliminate the most obvious non-homogeneous data from further analysis. Procedure is based on steps 1 and 4, Table 2, and steps 1 and 2, Table 3.
4. Compute regional indices	- pool regional data to maximize common regional trend components in homogeneous data sets - minimize local variability components in data series
5. F-test for significance of time versus regional variations in regional data series	- test the regional index matrices for significance of temporal versus geographic variations

1. Station history analysis.
2. Statistical testing of homogeneity, using various forms of the residual mass curve (WMO 1966), otherwise known as cumulative deviation curves (Buishand 1982), in combination with various tests of significance.
3. Analysis of double mass curve residuals.

2.1.1 Station history analysis

The primary source material for analysis of climate station history is the Station Catalogue of the Canadian Atmospheric Environment Service, which maintains all of the long-term climate stations in the Queen Charlotte Islands. The catalogue lists periods of station operation, location co-ordinates by latitude and longitude, and changes in location and instrumentation, and cross references any station name changes. Any changes listed in the catalogue, particularly location changes or interruptions of operation, are potential sources of non-homogeneity in the data series. The catalogue does not, however, include all the significant changes that have occurred at a station, particularly in the early years of station operation. This information can sometimes be found from periodic station inspection reports, and occasionally by compiling lists of station operators and matching their postal or residential addresses against the location co-ordinates in the station catalogue.

One specific, uncatalogued change in instrumentation has occurred at each of the three synoptic stations in the Queen Charlotte Islands. Coastal synoptic stations are located at airports or lighthouses, and transmit observations daily by radio as part of the weather forecasting service. Since 1960, all synoptic stations have had Nipher-shielded snow gauges installed. Snow catch efficiency may be enhanced considerably over the older snowboard, particularly in windy locations. The snow measurements at Nipher-shielded snow gauges are also affected by a change in the

method of calculating water equivalent. The snow catch is melted and measured volumetrically at the Nipher-shielded gauges. With the use of a snowboard, the snow water equivalent is assumed to be 1/10th of the snow depth, which generally underestimates the volumetric value. The combined effect of the increased catch efficiency and greater volumetric measurement of water equivalent result is an enhanced snowfall measurement at the Nipher-shielded snow gauges over the snowboard measurements, which may be sufficiently large to affect the homogeneity of the total precipitation data series at some stations.

2.1.2 Residual mass curve analysis

Residual mass curves, also known as cumulative deviation curves, are a family of related methods used primarily for data homogeneity analysis. Although included by the WMO in the list of methods not recommended for analysis of climate trends, Buishand (1982) found the curves useful in analyzing changes in data homogeneity. This study uses one form of this method -- the cumulative percent deviation curve as developed by Barrett[3] and applied by him -- to analysis of hydroclimatic trends in British Columbia.

The cumulative percent deviation method is based on the sequential deviations of annual (or seasonal) precipitation amounts from the mean for the period of record, expressed in percent. The sequential annual deviations are accumulated to determine the value for a given year, according to equation (1):

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[3]Barrett, G.E. 1979. Changes in the discharge of selected rivers in British Columbia during the period of instrumental records. Univ. of B.C., Dep. of Geography, Vancouver, B.C. Unpubl. honours essay.

$$y_i = 100 \cdot \Sigma ((x_i/\bar{x}) - 1) \qquad (1)$$

where y_i = cumulative percent departure from the mean to year i of the record

x_i = the precipitation value for year i

and $\bar{x}$ = the mean for period of record.

One of the attractions of this method is that it provides an excellent graphic representation of trends in the data series, particularly the timing of changes. It detects the timing and direction of changes in trend in data series, regardless of the source of the change. Thus, a change due to climate trend is indistinguishable from a change due to transfer of the station to another location or exposure. Separation of changes that are due to climate trends from other sources of change requires the analysis of double mass curve residuals.

2.1.3 Double mass curve residuals analysis

The analysis of double mass curve residuals compares the cumulative ratios of precipitation amounts at a base station assumed to have a homogeneous record, to a remote station with unknown data homogeneity, according to equation (2) (Craddock 1979).

$$s_i = \Sigma ((\bar{y}/\bar{x})x_i - y_i) \qquad (2)$$

where s_i = cumulative deviation of the observed total precipitation volume (mass) at the remote station up to the year i, from the expected total volume (mass), based on the ratio of annual means for the period of record at the base and remote stations and the observed total precipitation volume (mass) up to the year i at the base station.

$\bar{x}$ = base station mean for the period of record

$\bar{y}$ = remote station mean for the period of record

x_i = base station precipitation for year i

and y_i = remote station precipitation for year i.

As with the cumulative percent deviation method, good graphic representation of apparent changes in data homogeneity can be derived from this analysis. Changes in data homogeneity appear as a persistent change in the slope of the cumulative deviation graph. Analyses of several remote-base station relationships should be done to confirm changes in data homogeneity.

The homogeneity of the Yakoun River hydrometric record could not be tested against other regional hydrometric records because none were available. The Yakoun River record was therefore tested against the meteorological stations (Tasu Sound, Sandspit, Tlell) having the best correlation of October to April precipitation and the total water-year runoff, expressed in basin area-depth equivalents, using the double mass curve residual analysis technique.

2.2 Analysis of Regional Data Coherence

An interstation data correlation matrix was determined for all long-term and supplementary precipitation data. Correlation coefficients were calculated with a stock program on a TI 59 programmable calculator. Yakoun River water-year runoff data were also used, after the total runoff volume was converted into basin-area water depth equivalents.

2.3 Trend Analysis

Precipitation trends in the Queen Charlotte Islands were previously analyzed by Crowe (1960, 1963) and Powell (1966). Both analyzed the Masset precipitation series using the method of "n-year moving means", with 5- and 30-year base periods. Crowe concluded that "except for a minor decrease in the last two decades [1940's and 1950's], little

variation has occurred at Masset since 1915." Powell included Masset as one of three stations in an "Outer Coast" region, and concluded that annual precipitation on the outer coast had decreased from the period, 1901-1930, to the period, 1931-1960, in contrast to all other regions of British Columbia.

Both of these pioneering studies are, in retrospect, flawed by "hidden" data homogeneity problems at some of the stations selected, and by the method used for analysis. Both Crowe and Powell assumed that their data sets were homogeneous, and eschewed a more rigorous analysis of homogeneity. The Masset data series has a 9-year period from 1904 to 1912 during which recorded precipitation is suspiciously low. Moreover, the other two stations selected by Powell for the outer coast region (Clayoquot and Quatsino) have much more flagrant homogeneity problems, rendering his analysis invalid for this region.

The n-year moving mean method was, in all fairness to Crowe and Powell, the principal method used for climate trend analysis in British Columbia prior to 1979. Since then, its use has fallen into disfavour as a result of a re-evaluation of its efficacy relative to newer methods. The moving mean is one of the methods listed as "not recommended" for analysis of climatic trends by the WMO (1966). The main criticisms of the method are, as summarized by Barrett:[4]

- The choice of "n" is often arbitrary, yet it determines to a considerable degree the appearance of the smoothed record. Thus, records smoothed by different n-year moving mean filters will not be directly comparable.

- The use of moving means tends to obscure the timing of changes in stationarity.

- A single exceptional year in a stationary series may perturb that series for 2n - 1 years before and after the exceptional year.

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[4]Barrett, 1979.

- Use of the moving average process may induce an apparent periodicity of n-years, even in a random series.

- The effective length of record is reduced by (n-1)/2 years at either end of the record, and before and after any gaps in the record; i.e., there is a loss of n-1 years per record and n-1 years per gap.

To the above criticisms should be added a caution applicable to all methods of analysis based on a single series of data: the assumption of data homogeneity. If the record has significant changes in homogeneity as a result of changes in station location, exposure, or instrumentation, then any method of at-a-station analysis can show spurious, exaggerated, or diminished "climatic" trends, depending on the nature and timing of the change in homogeneity.

The analyses of data homogeneity (Section 2.1) and regional data coherence (Section 2.2) suggested that the Queen Charlotte Islands precipitation records are susceptible to misinterpretation if at-a-station methods, such as the n-year moving mean and cumulative percent deviation curves, were relied on exclusively for trend analysis. Therefore, a regional precipitation indexing method developed by Kraus (1977) was used instead. This indexing method is particularly appropriate in regions with relatively low interstation correlation, high incidence of changes at stations, and a generally fragmented long-term data base. By pooling the data base to maximize the common regional trend components and minimize local variations, regional indexing reduces the risk of identifying spurious trends and trend distortions The indexing method preferred by Kraus uses precipitation data normalized by equation (3):

$$P_{ij} = \frac{x_{ij} - \bar{x}_i}{\sigma i} \qquad (3)$$

where P_{ij} = the normalized October to April precipitation value at station i for year j

x_{ij} = the October to April precipitation at station i in the year j

$\bar{x}_i$ = the mean for the period of record at station i

and σ_i = the standard deviation for the period of record at station i.

The regional precipitation index for each season is calculated by averaging the normalized precipitation values of all stations having a record for that season, according to equation (4).

$$a_j = 1/I_j \sum_i p_{ij} \qquad (4)$$

where a_j = the regional precipitation index for the year j

I_j = the number of regional stations operating in the year j

and p_{ij} as defined previously.

Statistical tests for the significance of year to year variations in index values are based on standard analysis of variance methods. In particular, an F-test is used to determine the significance of time variance versus regional variance, according to the variance estimates in equations (5) and (6):

$$\text{Variance (time)} = \frac{\Sigma I_{ij} \cdot a_j^2}{J - 1} \qquad (5)$$

where J = the number of years in the period of analysis

and I_j, a_j as previously defined.

$$\text{Variance (regional)} = N - \frac{\Sigma I_j \cdot a_j^2}{N - J} \qquad (6)$$

where $N = \Sigma_j I_j = \Sigma_i J_i$ (the total number of station years)

and I_j, a_j as previously defined.

The same regional indexing procedure was used for winter temperature and water-year runoff volume data. In the latter instance, log transformed data were used, to reduce the effects of skewness of the distribution of the data on the normalization procedure.

2.4 Analysis of Trends in 1-Day Precipitation Amount and Frequency

Most slope failures and stream channel changes occur during short periods of more intense precipitation or streamflow. Such events do not necessarily occur during periods of generally above-average annual precipitation or stream runoff such as are identified by the analyses in Section 2.3. In the Queen Charlotte Islands, the shortest duration for which long-term precipitation data are available is the daily observation period (usually 0800 to 0800 hours). The fixed daily observation period usually masks the amount of the greatest 24-hour precipitation, by dividing it between two daily observation periods. At some non-synoptic stations run by volunteer observers, moreover, the daily observation schedule may lapse from time to time. For example, the daily schedule may be maintained only from Monday to Friday or Saturday. Precipitation during the period from the last observation on Friday or Saturday is combined in the first observation on Monday. This results in four or five legitimate 1-day precipitation measurements plus one reading which combines the precipitation over a 2- or 3-day period. The total precipitation recorded at such stations remains a homogeneous series, but the 1-day precipitation series is no longer useable, if the lapse in daily schedule persists over a period of time.

Four methods were used for the analysis of changes in the amounts and frequencies of 1-day precipitation. Three of the methods used the seasonal (October to April) maximum 1-day precipitation. The maximum 1-day precipitation series from each station (except Tasu Sound, Dead Tree Point, and Tlell) were analyzed using the cumulative percent deviation method and the indexing method described in Section 2.3 for analysis of seasonal (October to April) total precipitation. Log-transformed data were used for the indexing method to reduce the effects of skewness of the distribution of the data on the analysis.

The third method for analysis of maximum October to April 1-day precipitation involved a comparison between the maxima from the years with the highest, middle, and lowest thirds of seasonal (October to April) total precipitation amounts at each station. The 1-day maxima from the

years in the three classes were tested for significance of differences between the means of the classes with a standard F-test.

Sporns (1962) used a regional index of severe storm occurrences, based on the number of days in a year on which precipitation exceeded 100 mm at one or more observing stations in the lower Fraser Valley. Church and Miles (1986) updated this work. Application of this method to the Queen Charlotte Islands required lowering the 1-day precipitation defining a severe storm because of the different precipitation characteristics at the Queen Charlotte Islands stations. Exceedance thresholds for 1-day precipitation greater than 30 and 50 mm during each October to April season were chosen arbitrarily to represent moderately frequent 1-day precipitation (occurring at least twice a year on average) and infrequent 1-day precipitation (occurring less than once a year on average) at the leeward coastal stations on the Queen Charlotte Islands.

The analysis of 1-day precipitation exceedance frequencies required tallies of exceedance events (provided by the Canadian Climate Centre, Atmospheric Environment Service) as cumulative frequency tables of 1-day precipitation amounts, by month and year for each station (Appendix 1).

The October to April frequencies of 1-day precipitation exceeding 30 mm were compared between the years with the highest, middle, and lowest third of October to April total precipitation amounts at each station. The means of frequencies of events in each class were tested for significance of differences using a standard F-test.

3 RESULTS

The data analyses indicated that several of the meteorological stations on the Queen Charlotte Islands and the Yakoun River hydrometric station have questionable data homogeneity. Moreover, the entire Queen Charlotte Islands region has a relatively low coherence between stations. The homogeneity test results reinforced the validity of using the regional indexing approach for analysis of trends and fluctuations in hydroclimate variables in the Queen Charlotte Islands.

3.1 Data Homogeneity

The basic sources of information about data homogeneity are the detailed station histories (Appendix 2), cumulative percent deviation graphs, and analyses of double mass curve residuals. All must be combined for a comprehensive evaluation.

The meteorological station catalogue, if considered alone, suggests that of the eight long-term and supplementary stations available on the Queen Charlotte Islands, three have had no changes in their location (Langara, Sandspit Airport, and Dead Tree Point). Three others have had interruptions of operation and possible location changes (Tasu Sound, Cape St. James, and Queen Charlotte City). The remaining two, Tlell and Masset, have had location changes of several kilometres. Although not listed in the catalogue, Nipher-shielded snow gauges were installed at Langara, Cape St. James, and Sandspit Airport in the mid-1960's.

The cumulative percent deviation graphs for precipitation data (Figures 3, 4, 5, and 6) show periods of below-, near-, and above-normal precipitation as changes in the slope of the line. Periods of below-normal precipitation have a negative slope (downwards to the right); periods of above-normal precipitation have a positive slope (upwards to the right); near-normal periods have a zero slope. Points of change in the slope of the line identify the timing of changes between the various periods. The points of change from the various graphs have been plotted

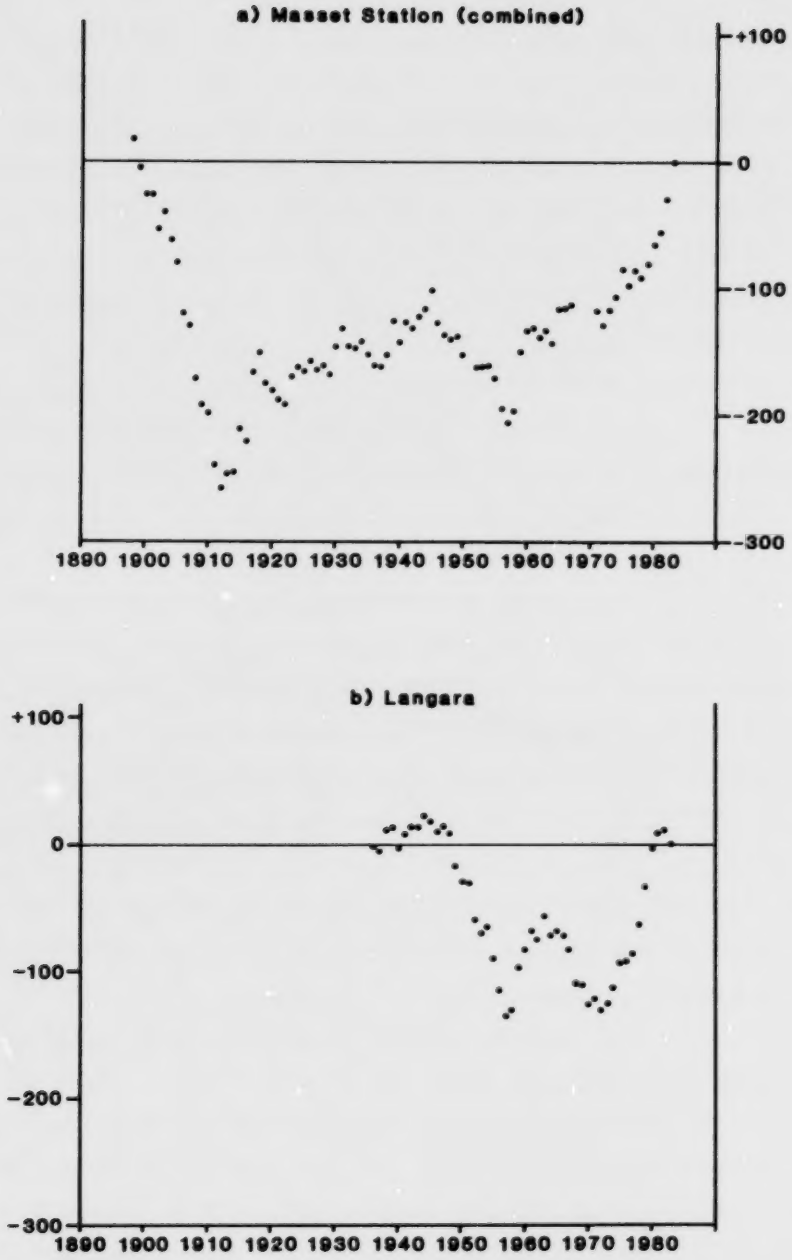

FIGURE 3. Cumulative percent deviation of October to April precipitation at Masset and Langara.

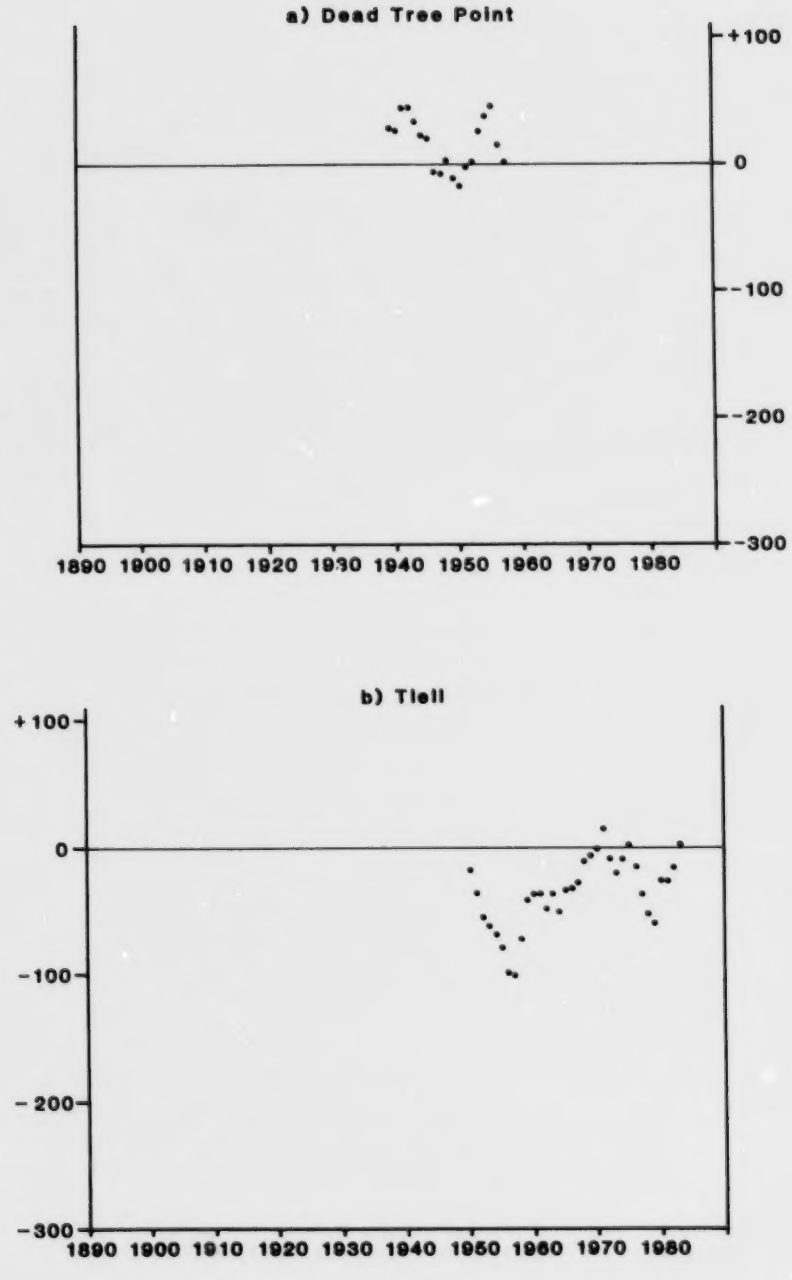

FIGURE 4. Cumulative percent deviation of October to April precipitation at Dead Tree Point and Tlell.

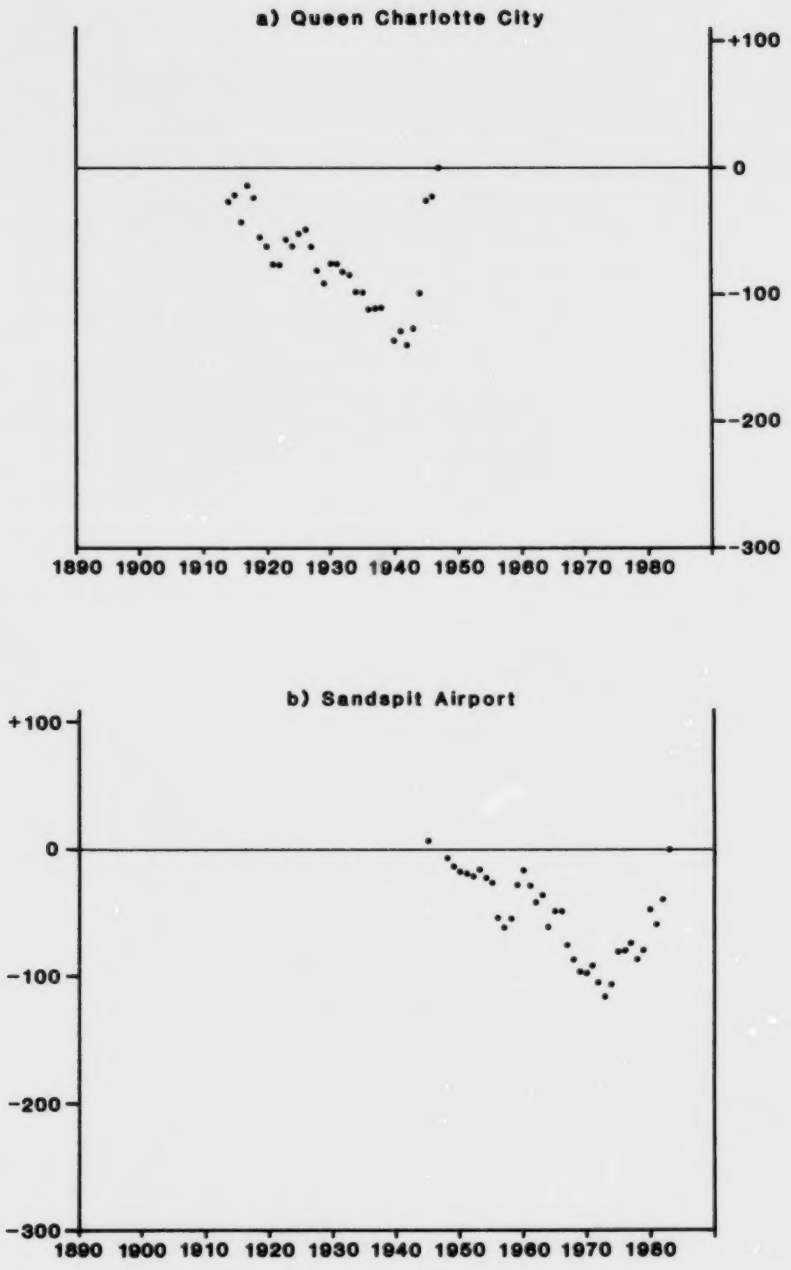

FIGURE 5. Cumulative percent deviation of October to April precipitation at Queen Charlotte City and Sandspit Airport.

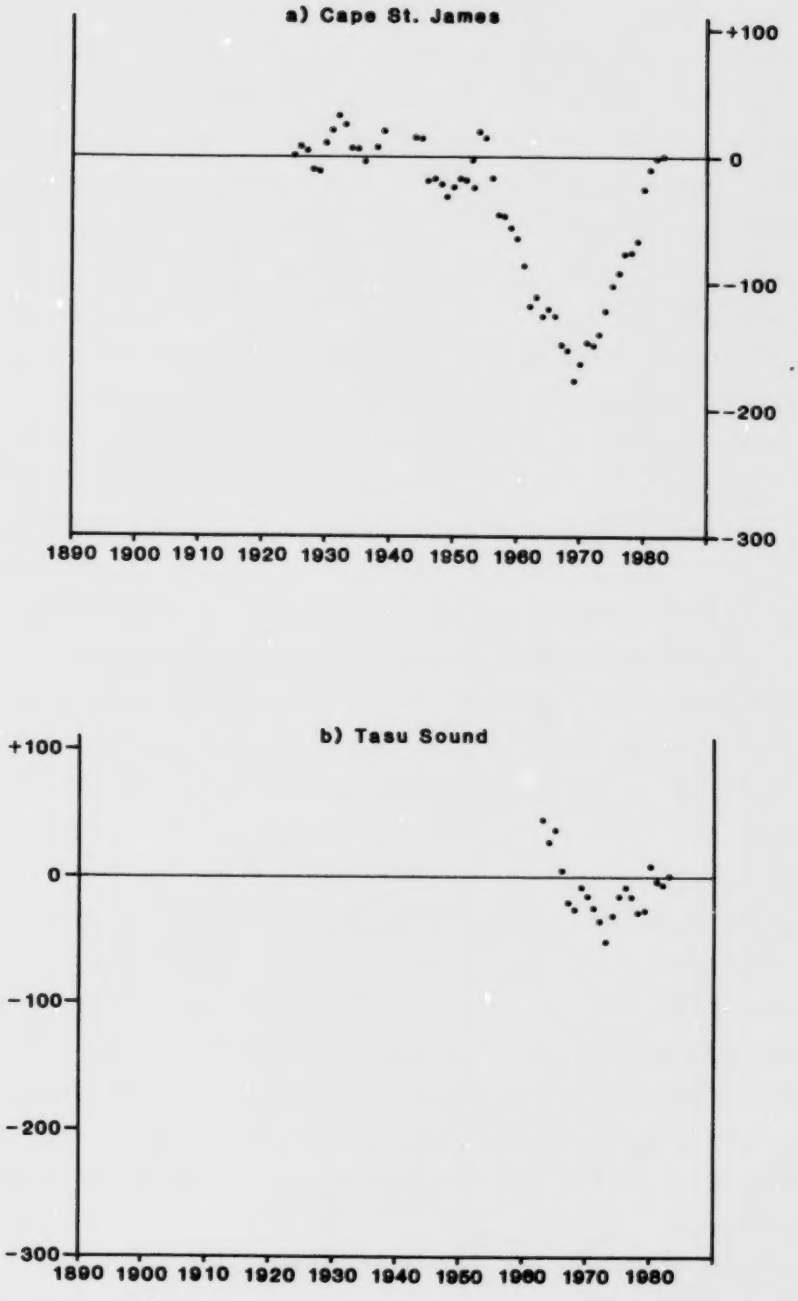

FIGURE 6. Cumulative percent deviation of October to April precipitation at Cape St. James and Tasu Sound.

schematically in Figure 7 to show the coincidences and disagreements between the graphs. The major coincidences are the beginnings of below-normal periods in 1918, 1932, 1946, and 1964, and above-normal periods in 1922, 1936, 1958, and 1974. The agreement among a number of stations on these dates indicates that the changes are probably climatic in origin. The main disagreements are at Queen Charlotte City in 1927 and 1942; Cape St. James in 1949, 1955, and 1969; Dead Tree Point in 1950; and Tlell in 1970 and 1979. In these instances the change appears to have occurred in isolation. In addition, there is the major perturbation in Masset data prior to 1913. Although these isolated changes are suspicious, the cumulative percent frequency graphs do not, by themselves, indicate whether the changes are due to local climate fluctuations or to station changes that have altered the homogeneity of the data series. Further analysis with double mass curve residuals and reference to the detailed station histories are required to resolve this distinction.

Figure 8 illustrates a composite example of double mass curve residuals analysis, and uses Masset as the remote station with unknown data homogeneity and a variety of base stations assumed to be homogeneous. As on the graphs of cumulative percent deviation, changes in the slope of the line and the points of change are the interpretive features on the graph. The points of change indicate shifts in the relationship of precipitation amounts between remote and base stations. In Figure 8, such changes appear to occur at Masset in 1904, 1913, and 1919. Only the change in 1913 is coincident with a known change in station location.

Composite graphs of double mass residuals were not produced for the other stations; analysis was done numerically. This indicated that in addition to the early Masset data (pre-1913), the Queen Charlotte City data after 1943 and the entire Tlell record should be rejected as non-homogeneous.

Analysis of double mass curve residuals also questioned the homogeneity of the Yakoun River hydrometric record. The annual runoff of the Yakoun River changes in relation to the precipitation at both Tasu Sound and Sandspit in 1968. (Tlell was not used for analysis because the

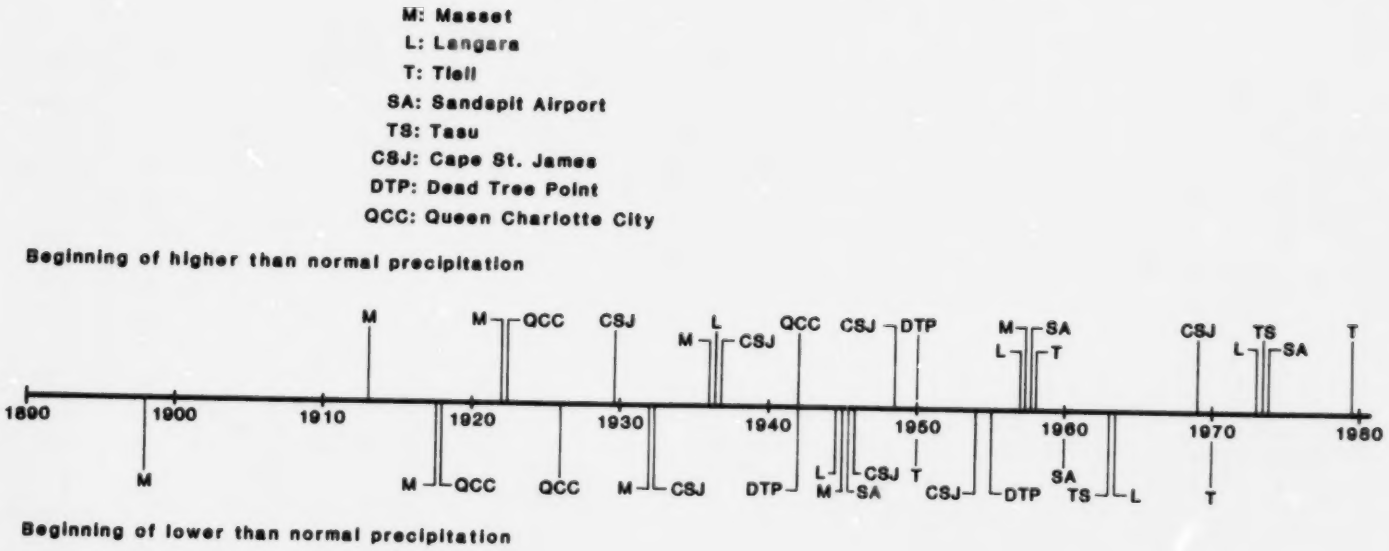

FIGURE 7. Timing of changes of cumulative percent deviation graphs of October to April precipitation at Queen Charlotte Islands stations.

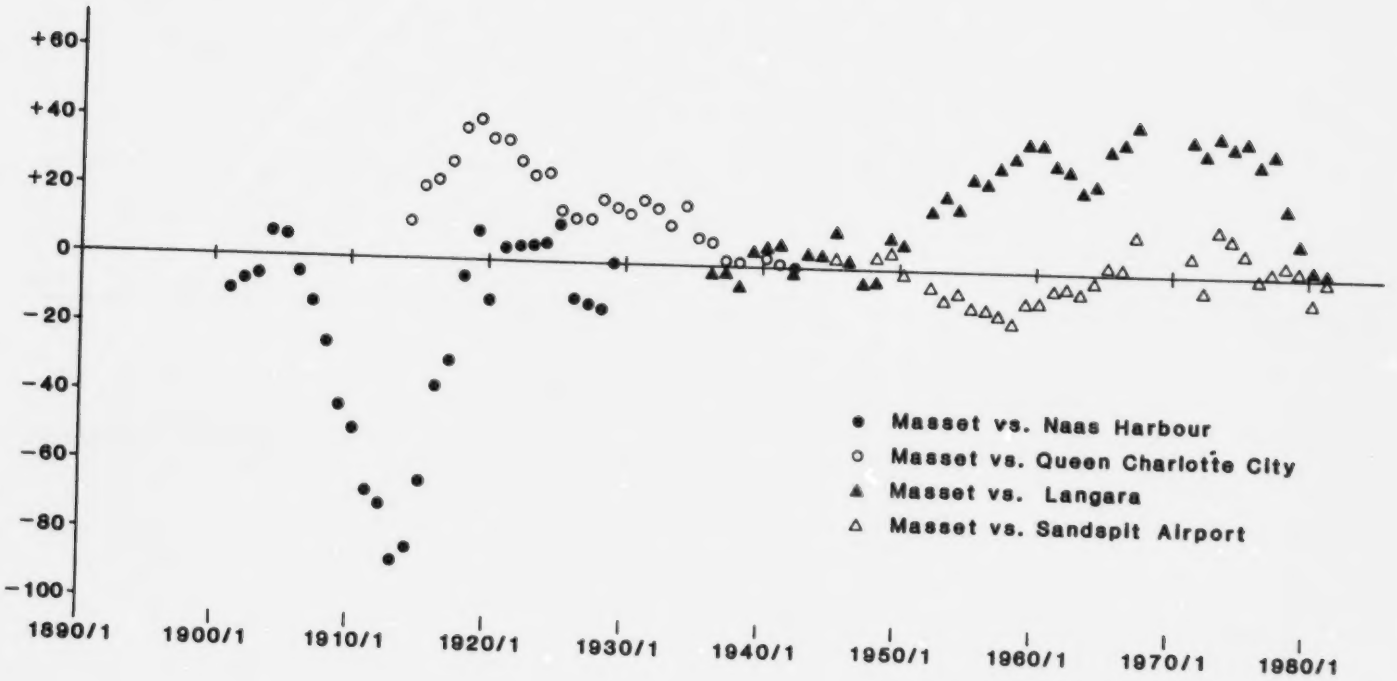

FIGURE 8. Composite graphs of double mass curve residuals for Masset October to April precipitation data.

homogeneity of the Tlell record was already rejected above.) The change coincided with an 8-month gap in the Yakoun River record, which suggested changes in either the channel transect or the water level gauging station when the station was re-established.

The effects of Nipher-shielded snow gauge installations at Langara, Sandspit Airport, and Cape St. James were examined with cumulative percent deviation curves for winter snowfall at all the Queen Charlotte Islands stations (Figures 9, 10, and 11). The snowfall data show that the largest effects have occurred at Langara and especially at Cape St. James, while little effect has been observed at Sandspit Airport. This result is not surprising, since Langara and Cape St. James are undoubtedly the windiest meteorological stations on the Queen Charlotte Islands, and the catch efficiency of the Nipher gauge compared to snowboards increases with windspeed. Although snowfall accounts for only 3 and 7% of total October to April precipitation over the periods of record at Cape St. James and Langara, respectively, a comparison of the pre- and post-Nipher gauge installation periods shows a substantial increase in snowfall as a portion of total precipitation at these two stations. At Cape St. James, snowfall increased from 1.6 to 5.9% of total October to April precipitation, while the increase at Langara was from 4.9 to 9.3%. Changes for the same periods at Sandspit Airport were from 7.1 to 8.4%, and at Masset from 6.8 to 7.6%. The October to April rainfall (precipitation minus snowfall) records at Langara and Cape St. James are probably more homogeneous than the total precipitation records.

The detailed station histories and results of data homogeneity analysis with the cumulative percent deviation graphs and double mass curve residuals are summarized in Figure 12. This shows that the only station on the Queen Charlotte Islands that has not changed during its operation is Dead Tree Point, which has a relatively short record and was discontinued in 1958.

In summary, the following changes in Queen Charlotte Islands stations and data homogeneity have been inferred:

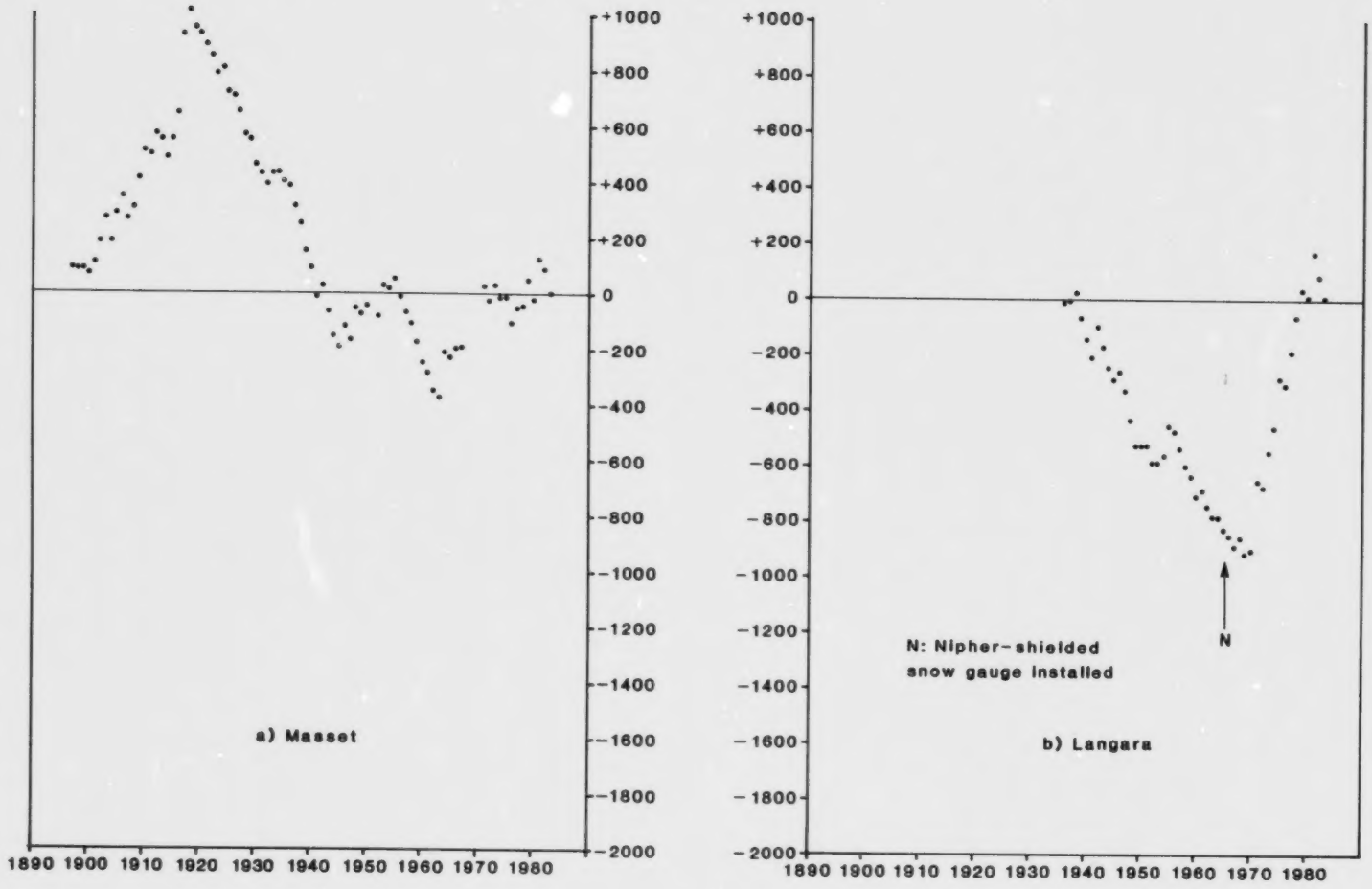

FIGURE 9. Cumulative percent deviation of winter snowfall at Masset and Langara.

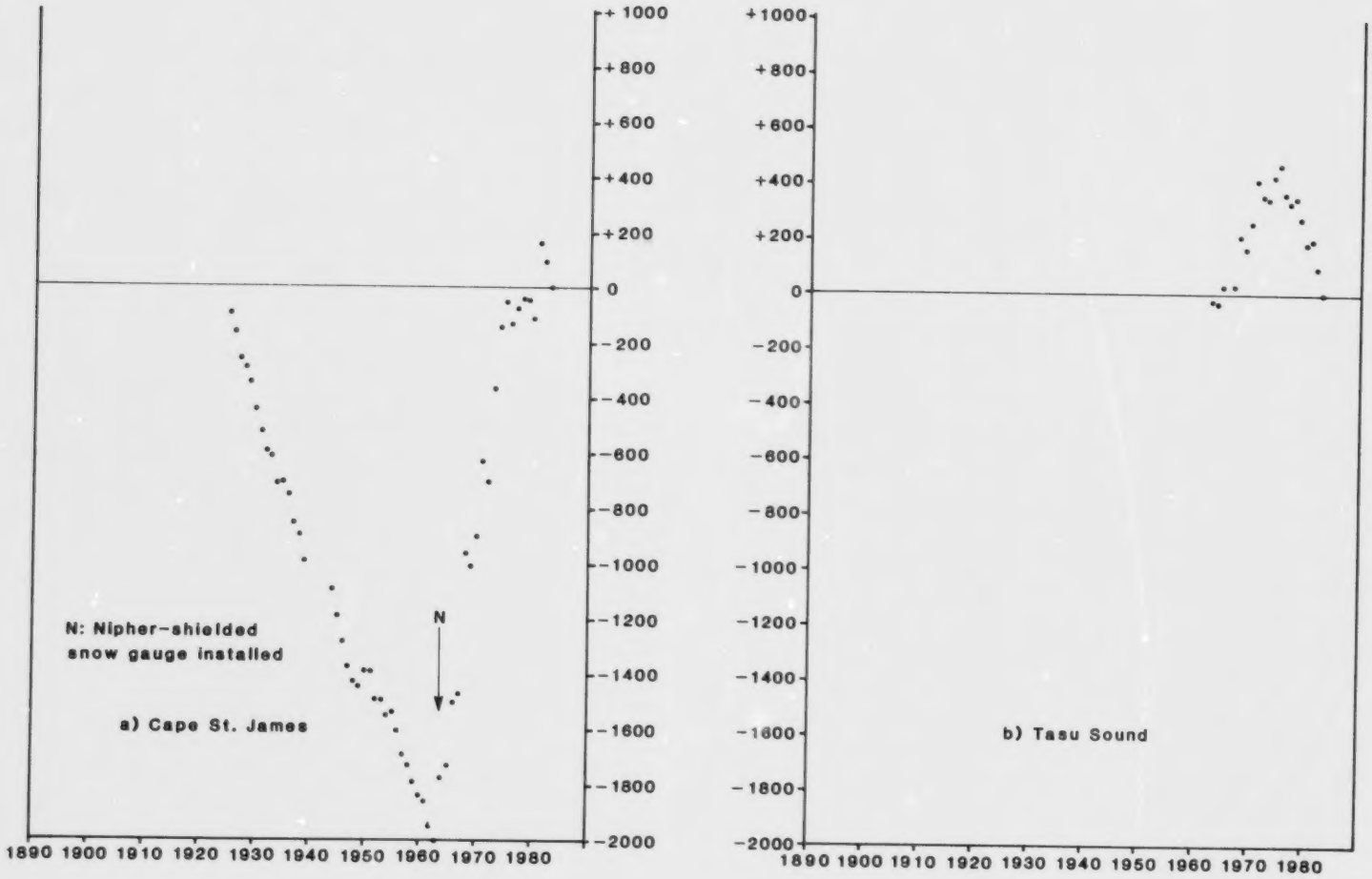

FIGURE 10. Cumulative percent deviation of winter snowfall at Cape St. James and Tasu Sound.

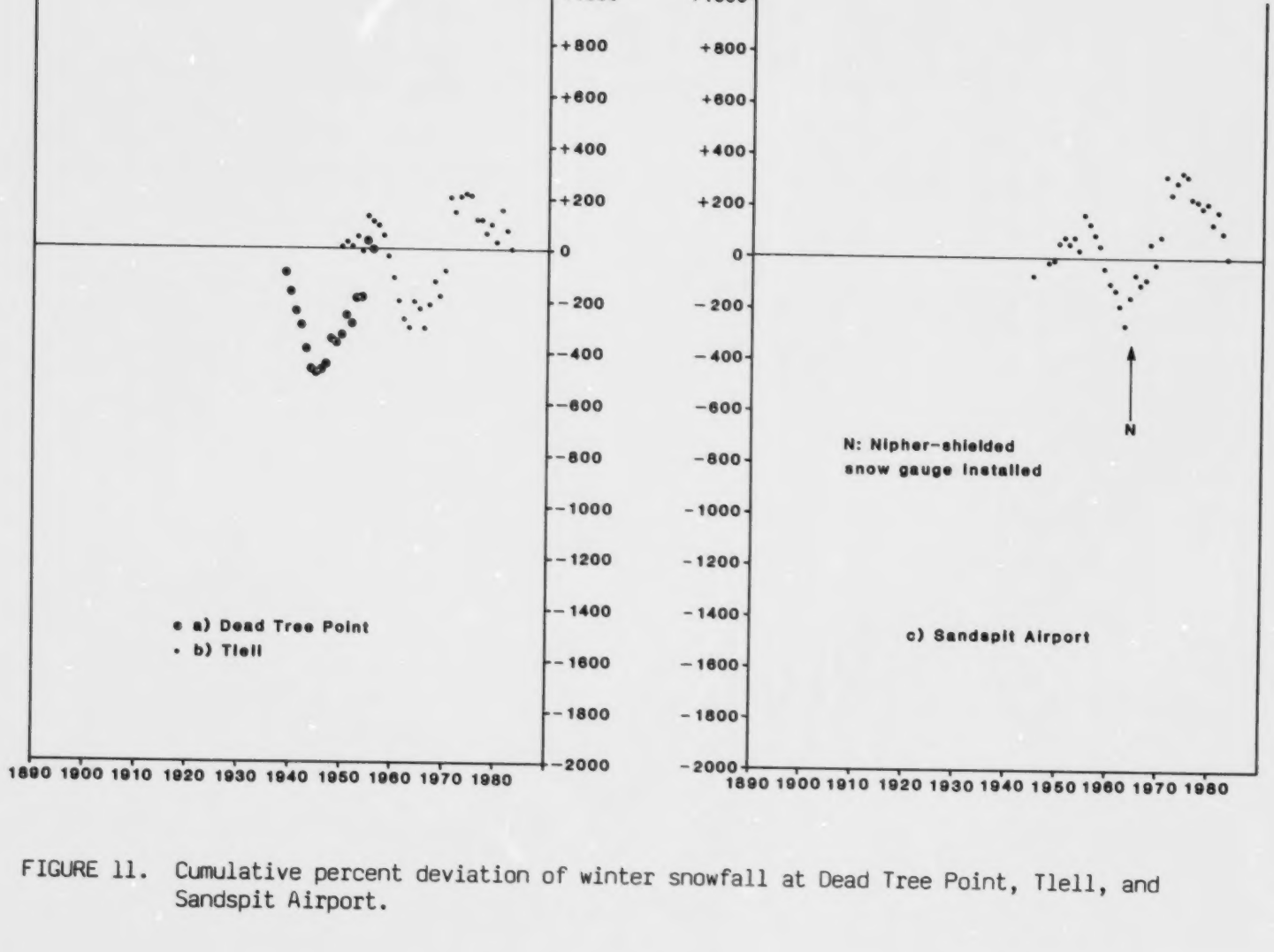

FIGURE 11. Cumulative percent deviation of winter snowfall at Dead Tree Point, Tlell, and Sandspit Airport.

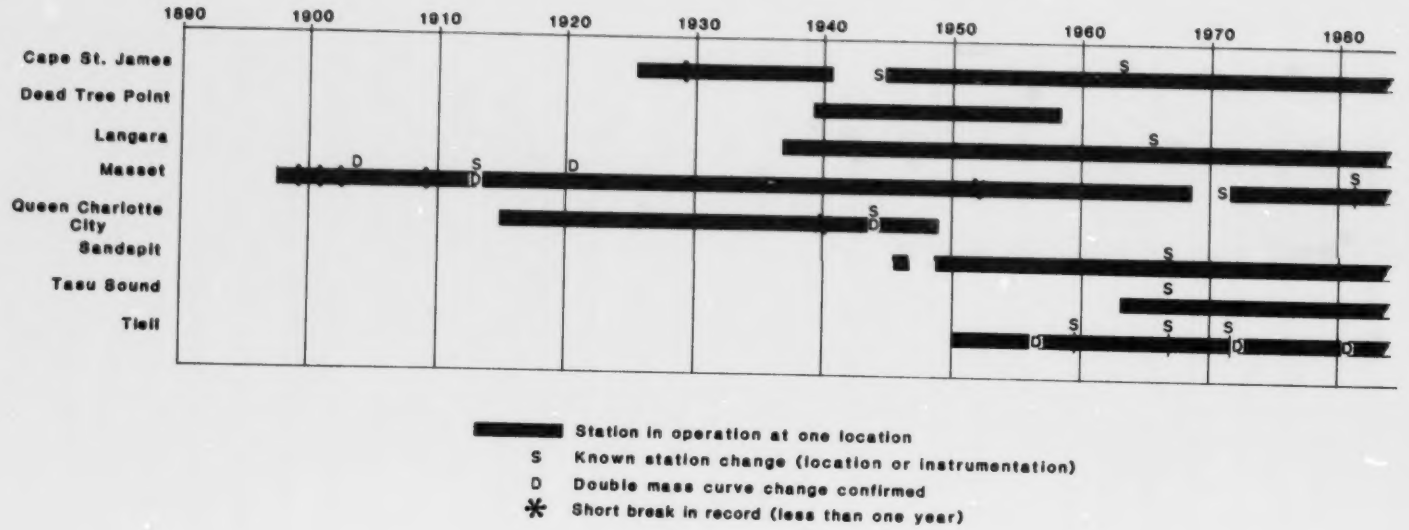

FIGURE 12. Summary of station histories for Queen Charlotte Islands regional precipitation index.

- At Masset, the 1904-1913 data are much too low even for a dry period. The post-1971 data should have -- but apparently did not -- become progressively drier as the station location moved further east.
- At Langara, Cape St. James, and Sandspit Airport the installation of Nipher-shielded snow gauges in the 1960's increased the amount of snowfall recorded, and probably has affected the homogeneity of precipitation data at Langara and Cape St. James.
- The Queen Charlotte City station was apparently moved further west in 1943, significantly increasing the recorded precipitation.
- The Tlell station has been moved several times, and was for a period located in a bad exposure (R. Marsh, pers. comm.)
- The Yakoun River hydrometric station apparently had a change in the channel transect or the water level gauging station in 1968.

On the basis of the above information, three records were rejected for inclusion in the regional precipitation index for analysis of trends. The pre-1914 Masset record was rejected because it appears to be much too low during a 9-year period from 1904 to 1913, and cannot be corroborated by other Queen Charlotte Islands data. After 1913, the Queen Charlotte City data provide a reasonable backup. The Queen Charlotte City data after 1943 were rejected because of the station's apparent move to a much wetter location. Finally, the entire Tlell record was rejected because of several moves, including one to a poor raingauge exposure.

3.2 Regional Data Coherence

Correlations between stations can indicate the scale of processes that affect regional precipitation, while anomalies in correlations can indicate data homogeneity problems at individual stations. Interstation correlations were done for October to April precipitation, water-year runoff volume, and winter temperature. Regional coherence of snowfall was analyzed by examining the cumulative percent deviation graphs.

3.2.1 Precipitation data

The Queen Charlotte Islands, like much of north coastal British Columbia, has relatively low correlation of precipitation between stations, particularly when compared to Vancouver Island. October to April precipitation correlation coefficients greater than r=0.7 are rare among the long-term Queen Charlotte Islands stations, and occur mainly between some older data sets from 1915 to 1957 (Table 4). The best overall coherence occurs among the northeast coastal stations between Masset and Sandspit Airport. The average of the correlation coefficients of stations in this area is about r=0.65, in a low-lying area about 90 km long, covering a narrow strip along the eastern coast. By comparison, the long-term stations on northern Vancouver Island have an average correlation coefficient of about r=0.85, in an area about 90 km long but including both leeward and windward stations. In fact, on northern Vancouver Island, correlation coefficients less than r=0.75 were a fairly reliable indicator of a data homogeneity problem in one of the data sets.

The relatively low correlation coefficients on the Queen Charlotte Islands suggests that trends in the precipitation data from the leeward east coastal stations may not be representative of trends in the windward west coast area. Moreover, they suggest that small scale local influences on autumn/winter precipitation are more important on the Queen Charlotte Islands than on Vancouver Island, which is a more coherent unit.

3.2.2 Snowfall data

Correlation coefficients were not calculated for snowfall data. Examination of the cumulative percent deviation graphs for snowfall (Figures 9, 10, and 11) shows that general periods of below- and above-normal snowfall have occurred concurrently at most stations. The exceptions are Langara and Cape St. James, where trends are dominated by the change in catch efficiency resulting from the installation of Nipher-shielded snow gauges.

TABLE 4. Interstation correlation coefficients for October to April precipitation on the Queen Charlotte Islands

Langara	Masset	Tlell	Dead Tree Point	Queen Charlotte City	Sandspit	Yakoun	Tasu	Cape St. James
.64								
.43	.65							
.36	.65	*						
*	.76	*	*					
.59	.69	.59	.64	*				
.07	.51	.68	*	*	.50			
.49	.35	.51	*	*	.70	.69		
.44	.40	.20	.86	.77	.60	.06	.43	

* Indicates insufficient data (less than 10 values)

3.2.3 Stream runoff data

Analysis of regional coherence was not possible for the stream-gauging stations on the Yakoun River on Graham Island and Old Tom Creek on Prince of Wales Island because of their isolation from other long-term hydrometric stations. The Yakoun River water-year runoff volumes were converted to basin depth equivalents for comparison with the October to April precipitation at the meteorological stations. Correlation coefficients were in the same range (0.5-0.7) as between the precipitation data (Table 4).

Correlation coefficients on Revillagigedo Island are comparable to October to April precipitation coefficients on northern Vancouver Island, ranging from r=0.78 to r=0.91 (Table 5). It is apparent that runoff is fairly coherent on Revillagigedo Island.

3.2.4 Winter temperature data

Mean temperatures, especially during a 4-month period (December to March) are generally coherent across a wider area than is precipitation. Correlation coefficients between Langara, Masset, Port Simpson, and Prince Rupert ranged from 0.86 to 0.96 for monthly mean temperatures in December, January, February, and March.

3.3 Regional Trends

Climate trends in the Queen Charlotte Islands are shown as regional indices for October to April precipitation and rainfall, and December to March mean temperature. Water-year runoff volume on Revillagigedo Island is also shown as a regional index. Both the annual (seasonal) and cumulative index values are shown on the graphs. The cumulative value illustrates trends in the same way as cumulative percent frequency curves do: a negative slope indicates below-average conditions, a positive slope indicates above-average conditions, and a neutral slope indicates average conditions.

TABLE 5. Interstation correlation coefficients of water-year runoff volume at Revillagigedo Island hydrometric stations

	Fish Creek	Winstanley Creek	Manzanita Creek	Mahoney Creek
Fish Creek				
Winstanley Creek	.86			
Manzanita Creek	.91	.88		
Mahoney Creek	.89	.78	.85	

A regional index could not be constructed for snowfall data because of the extreme skewness of the data. Old Tom Creek, being relatively isolated from the other hydrometric stations, was excluded from the Revillagigedo Island regional runoff volume index. Trends in the snowfall data and the excluded set of runoff volumes are interpreted from their individual cumulative percent deviation graphs (Figures 9-11, 13).

3.3.1 October to April precipitation trends

The precipitation index for the Queen Charlotte Islands was calculated from the stations at Masset (excluding pre-1914 data), Queen Charlotte City (excluding post-1943 data), Dead Tree Point, Sandspit Airport, Langara, and Tasu Sound. Tlell was excluded because of the data homogeneity problem at this station, and Cape St. James was excluded because of its isolation from the other stations and poor correlation coefficients with most of the other data series.

The precipitation index is shown in Figure 14, and the matrix of index values is in Appendix 3.

The cumulative precipitation index shows that the central and northern Queen Charlotte Islands have undergone five episodes since 1914. The precipitation for the 30-year period from 1914/15 to 1945/46 approximated the long-term mean, as was suggested earlier by Crowe (1960). During this period there were four short periods with above-normal precipitation: 1915/16-1918/19; 1923/24-1926/27; 1930/31-1931/32; and 1938/39-1941/42. Periods of below-normal precipitation intervened. Five of the 10 highest index values occurred during these short periods of above-normal precipitation.

Two longer periods of below- and above-normal precipitation have alternated since 1945/46. The two drier periods occurred from 1946/47 to 1957/58 and from about 1964/65 to 1973/74. October to April precipitation averaged between 7 and 12% below the long-term mean during these periods. The periods of above-normal precipitation occurred from 1958/59 to 1963/64 and from 1974/75 to 1983/84. Autumn/winter precipitation has averaged from 8 to 19% above the long-term mean during these periods. Since 1974/75, the central and

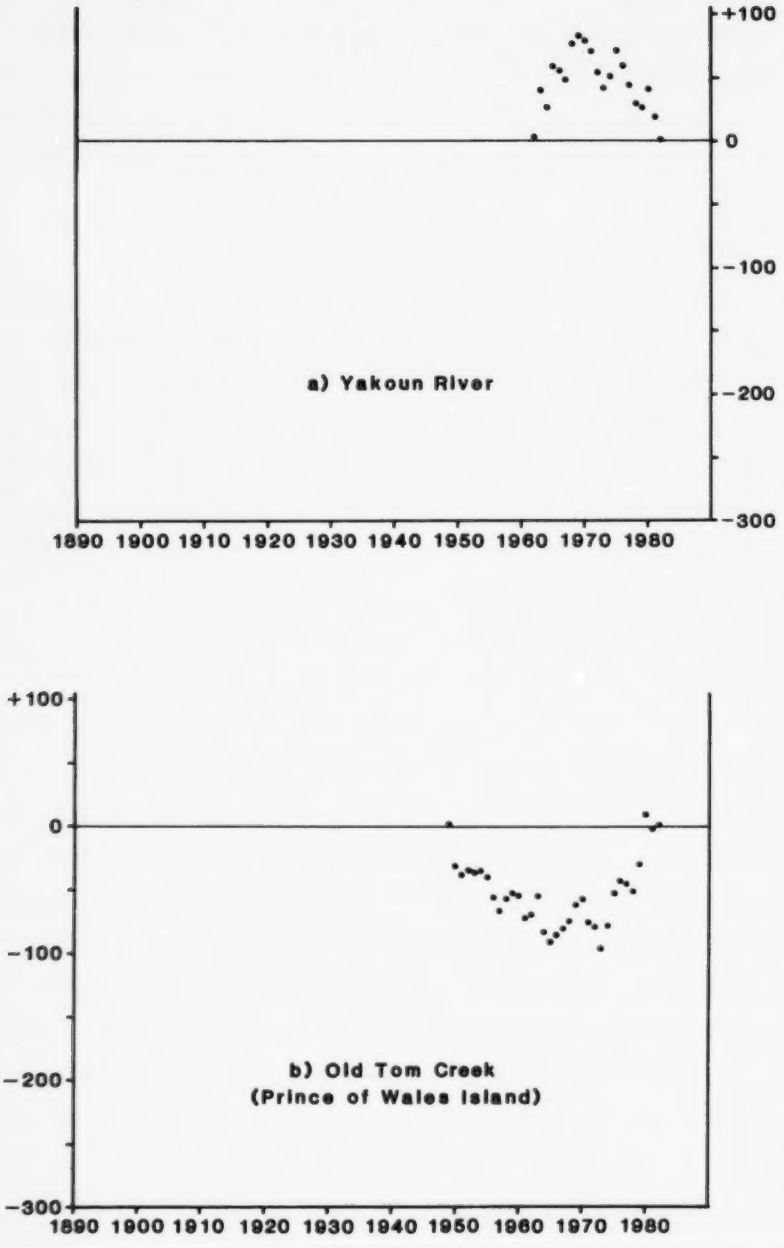

FIGURE 13. Cumulative percent deviation of winter-year runoff volume in the Yakoun River and Old Tom Creek.

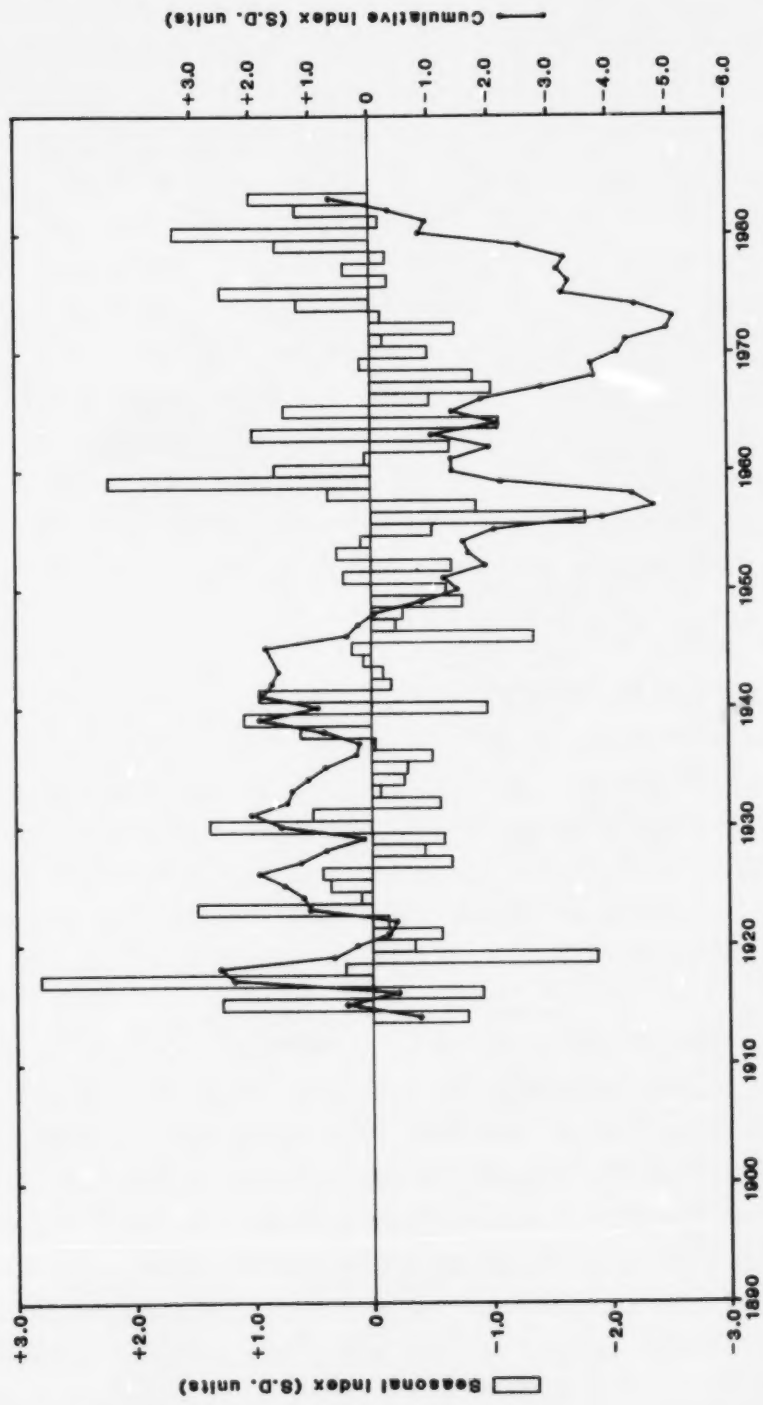

FIGURE 14. October to April seasonal and cumulative precipitation index for central and northern Queen Charlotte Islands.

northern Queen Charlottes have been experiencing the longest sustained period of above-normal precipitation since the beginning of records. Included in this period are 3 years that were wet throughout the area covered by the index (1974/75, 1975/76, and 1980/81). During 4 of the years in this period, index values were highest along the north coast of Graham Island (1977/78-1979/80, and 1981/82). During the most recent 2 years (1982/83-1983/84), the locus of highest indices shifted to the east coast between Sandspit and Masset. Three of the 10 highest regional index values have occurred during this period.

The Masset data prior to 1914/15 suggest a lengthy dry period occurred from 1898 to 1913. While these data have been rejected on the basis of homogeneity analysis, other data from north coastal British Columbia and the Alaska Panhandle corroborate the occurrence of a dry period, but one not as severe as that implied by the Masset data.

3.3.2 October to April rainfall trends

The regional index for October to April rainfall (Figure 15) shows one difference from the precipitation index. Although the same short fluctuations between below- and above-normal periods were evident for both indices between 1914/15 and 1945/46, the period from 1923/24 to 1945/46 on the whole had above-normal rainfall. The above-normal rainfall is particularly evident from 1938/39 to 1945/46.

3.3.3 October to April snowfall trends

All of the meteorological stations on the Queen Charlotte Islands are located at less than 200 m elevation. Snowfall trends at these low-elevation stations do not necessarily represent trends at elevations above the semi-permanent winter snowline at around 500-700 m. The cumulative percent deviation graphs of winter snowfall indicate periods of below-normal snowfall from 1919/20 to 1945/46, 1956/57 to 1963/64, and 1976/77 to 1983/84. Above-normal

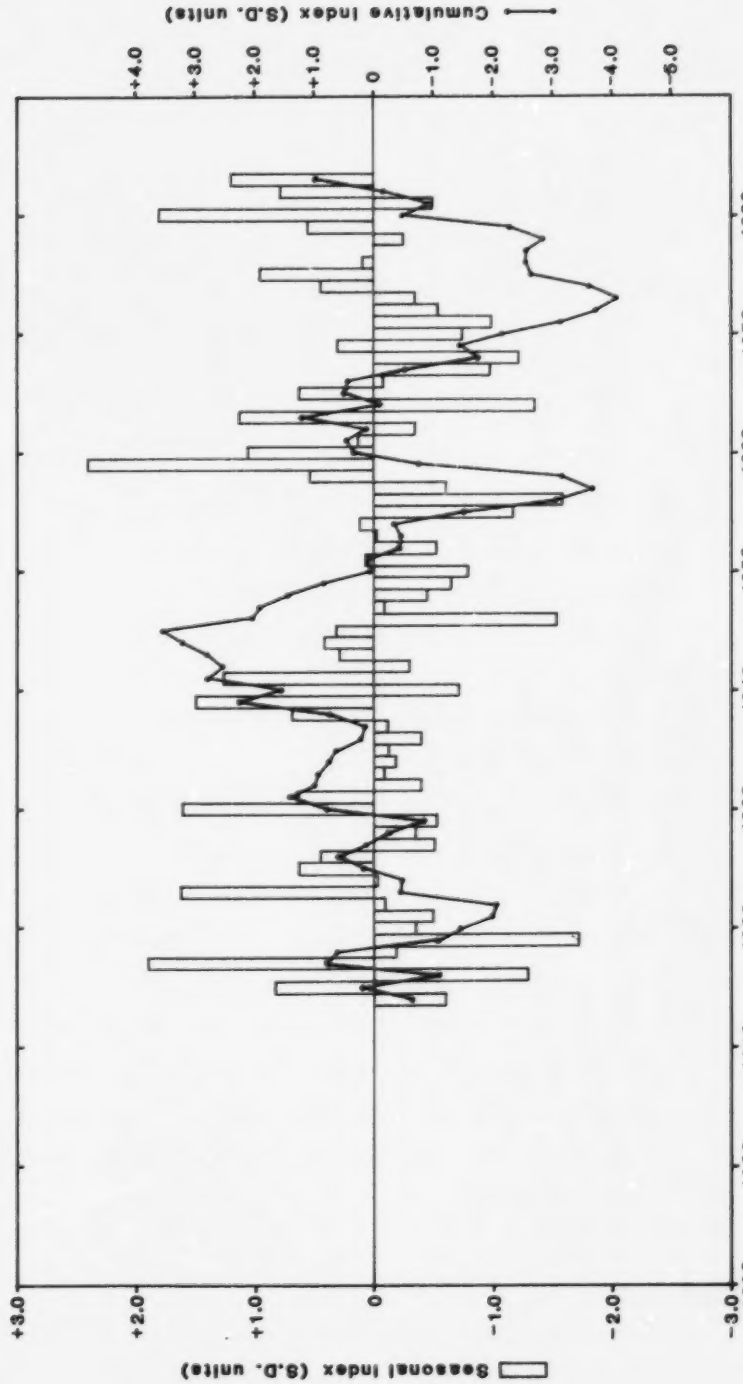

FIGURE 15. October to April seasonal and cumulative rainfall index for central and northern Queen Charlotte Islands.

periods intervened from 1946/47 to 1955/56 and 1964/65 to 1975/76. Langara and Cape St. James were excluded from analysis of snowfall trends because of the perturbation caused by installation of Nipher-shielded snow gauges in the mid-1960's.

3.3.4 Water-year runoff volume trends

Revillagigedo Island

The water-year runoff volume index for Revillagigedo Island (Figure 16) shows both similarities to and differences from the precipitation and rainfall indices for the Queen Charlotte Islands. The main similarities are:

- The period from 1915/16 to 1939/40 has runoff volumes near the long-term mean overall, with short fluctuations between below- and above-normal amounts that correspond to those of Queen Charlotte Islands precipitation.
- The period from 1940/41 to 1957/58 has below-normal runoff volumes. This period is interrupted by 3 years of above-normal runoff, which are not distinguishable in the Queen Charlotte Islands precipitation/rainfall indices.
- The period from 1958/59 to 1963/64 has runoff much above normal, corresponding to the Queen Charlotte Islands data.

The major differences between the Queen Charlotte Islands precipitation/rainfall indices and the Revillagigedo Island runoff index have occurred since 1963/64. The Queen Charlotte Islands precipitation and rainfall are below normal from 1964/65 to 1973/74 and above normal since 1974/75. By contrast, the runoff index for Revillagigedo Island remains near normal from 1964/65 to 1973/74, but has been below normal since 1973/74, except for the 3 years 1974/75, 1975/76, and 1980/81.

Yakoun River

The Yakoun River hydrometric record was rejected on the basis of data homogeneity analysis. The trends shown in the cumulative

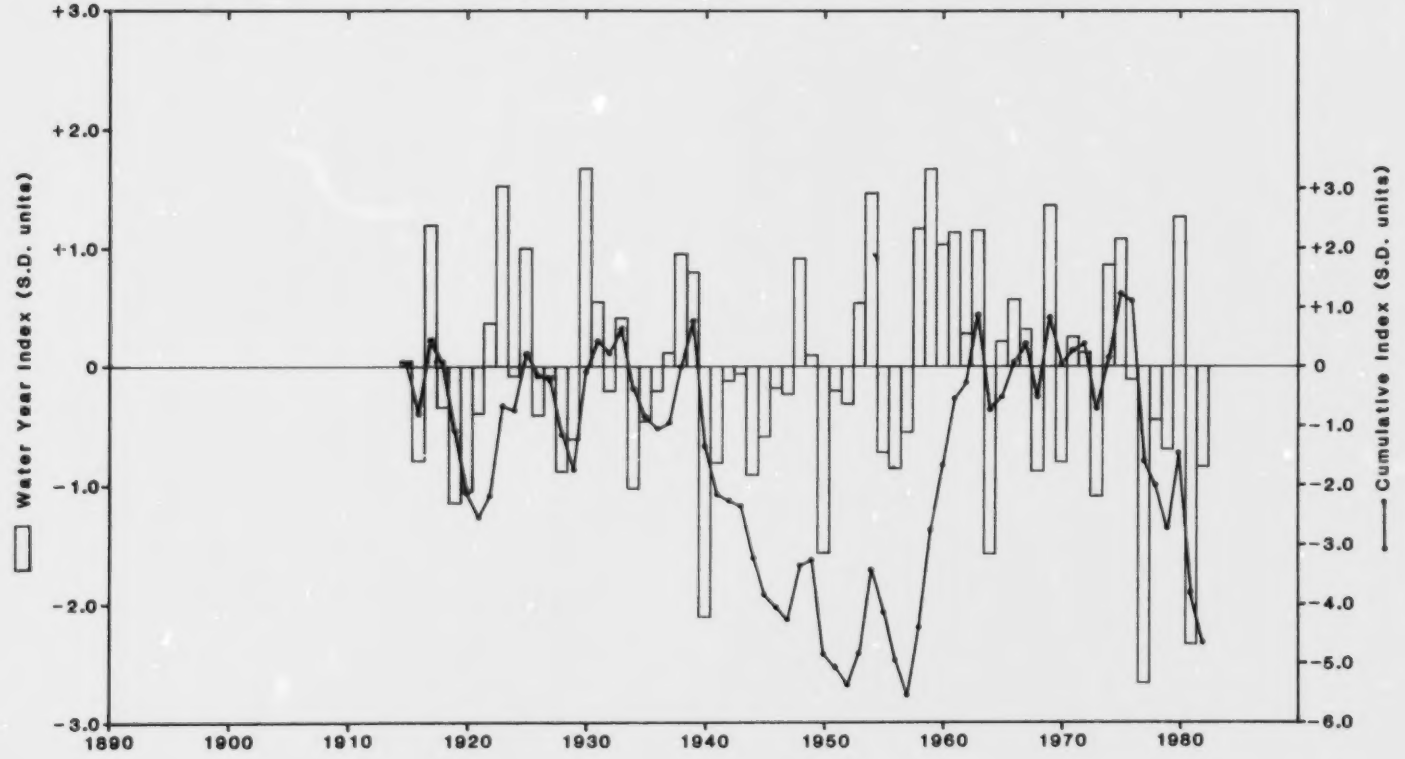

FIGURE 16. Water-year and cumulative runoff volume index for Revillagigedo Island, Alaska.

percent deviation graph (Figure 13a) of runoff volume are contrary to the trends in both the regional precipitation index and the cumulative percent deviation graphs of precipitation at individual stations.

Prince of Wales Island

Trends in the cumulative percent deviation graph of runoff volumes in Old Tom Creek, Prince of Wales Island (Figure 13b), differ from Revillagigedo. Runoff volumes were generally below the long-term mean from 1949/50 (beginning of records) to 1965/66. The above-normal period from 1958/59 to 1963/64, which is a feature in both the Queen Charlotte Islands precipitation index and the Revillagigedo Island runoff index, is nearly absent from the Old Tom Creek data. On the other hand, the above-normal period of runoff from 1974/75 to 1980/81 in Old Tom Creek duplicates the trend in the Queen Charlotte Islands precipitation index, but is in sharp contrast to trends in runoff volumes on Revillagigedo Island.

3.3.5 Winter (December to March) mean temperature trends

The temperature records from Langara, Masset, Port Simpson, and Prince Rupert were combined to construct a winter temperature index for the northern Queen Charlotte Islands - northern British Columbia coast area (Figure 17). The cumulative index shows periods of above-normal temperature from 1896/97 to 1905/06, 1911/12 to 1914/15, 1925/26 to 1931/32, 1937/38 to 1945/46, 1957/58 to 1963/64, and 1976/77 to 1983/84. All of the post-1914/15 periods coincide with periods of above-normal precipitation or rainfall and below-normal snowfall on the Queen Charlotte Islands. The periods of below-normal temperatures (1915/16 to 1922/23, 1932/33 to 1936/37, 1946/47 to 1956/57, and 1964/65 to 1975/76) coincide with periods of below-normal precipitation and rainfall, and above-normal snowfall. The coincidental timing is discussed further in Section 4.1.

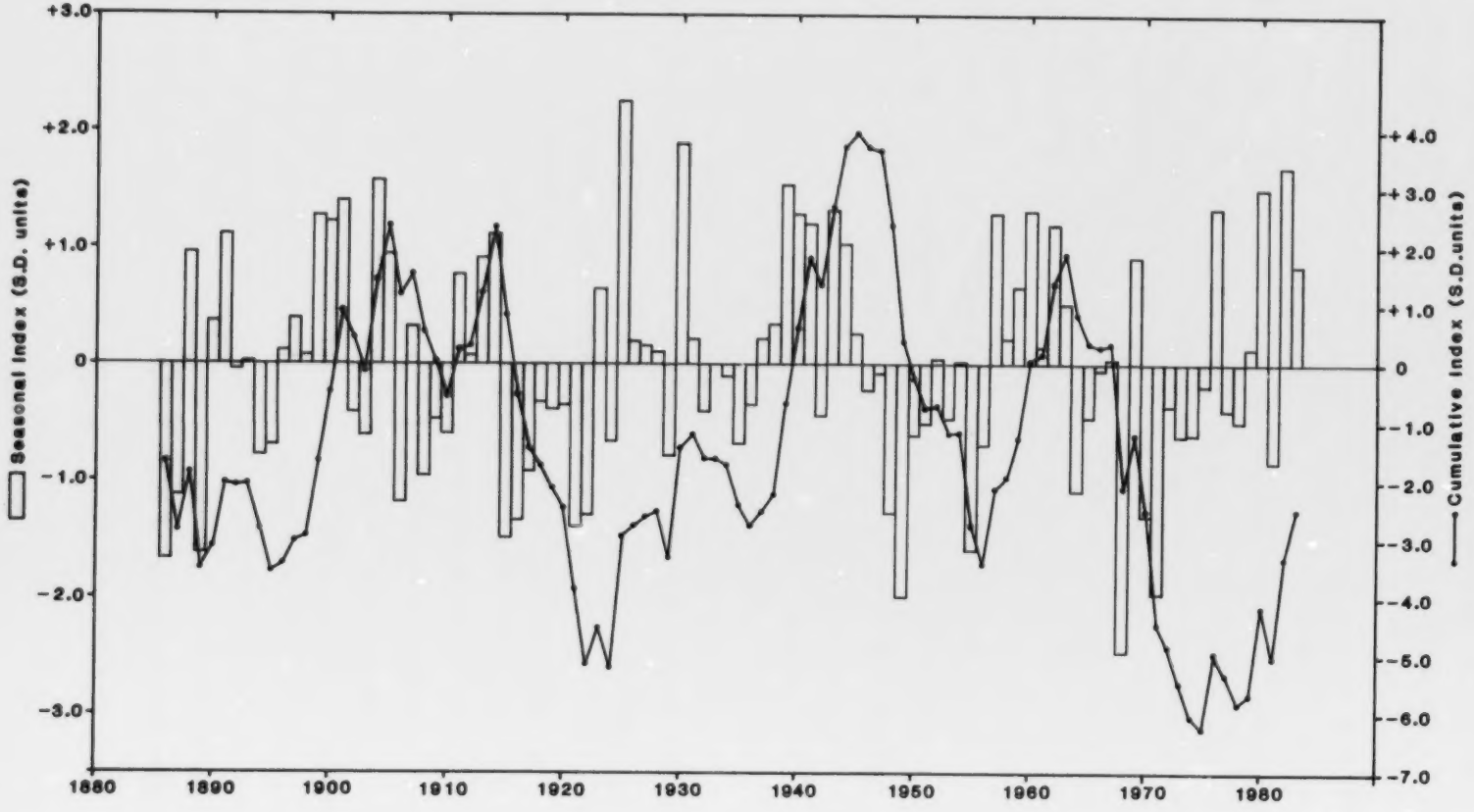

FIGURE 17. December to March seasonal and cumulative mean temperature index for northern Queen Charlotte Islands.

3.3.6 One-day precipitation trends

Trends in 1-day maximum precipitation were analyzed for Masset, Langara, Queen Charlotte City, Sandspit, and Cape St. James. The Tlell, pre-1914 Masset, and post-1943 Queen Charlotte City data were deleted to ensure data consistency as previously discussed. The data from Masset Canadian Forces Station (CFS) and Tasu Sound also had to be deleted from the 1-day precipitation analysis. It was determined that some irregularities in the data series from the latter two stations were due to changes in the daily observation schedules. Tasu Sound changed from a schedule of regular twice-daily observations to a schedule of Monday to Friday twice-daily observations in 1980. Weekend precipitation amounts were recorded thereafter as a combined Friday evening to Monday morning total. Thus, the Tasu Sound record becomes unusable for analysis of daily precipitation after 1980. Similarly, the Masset CFS record has periods with no weekend readings, as well as irregular, longer combinations of daily precipitation amounts beginning in 1978.

The cumulative percent deviation graphs of the annual maximum 1-day precipitation (Figures 18 and 19) indicate periods of greater than average annual maxima from 1914/15 to 1923/24, 1933/34 to 1935/36, 1950/51 to 1953/54 (south only), 1957/58 to 1962/63 (north only), 1969/70 to 1972/73 (Langara only), and 1978/79 to 1983/84. All of these periods, except the period beginning in 1950/51 coincide with periods of greater than average October to April precipitation.

The regional index of annual maximum 1-day precipitation for the central and northern Queen Charlotte Islands (Queen Charlotte City, Masset, Sandspit, and Langara) indicates general periods of above-average annual maxima from 1914/15 to 1935/36 and 1977/78 to 1983/84. A long period of generally below-average maxima intervenes (Figure 20). The most notable feature of the regional index is that 5 out of the 18 highest values have occurred since 1978/79, an unbroken concentration unprecedented in the validated record. While other concentrations of high indices have occurred from 1914/15 to

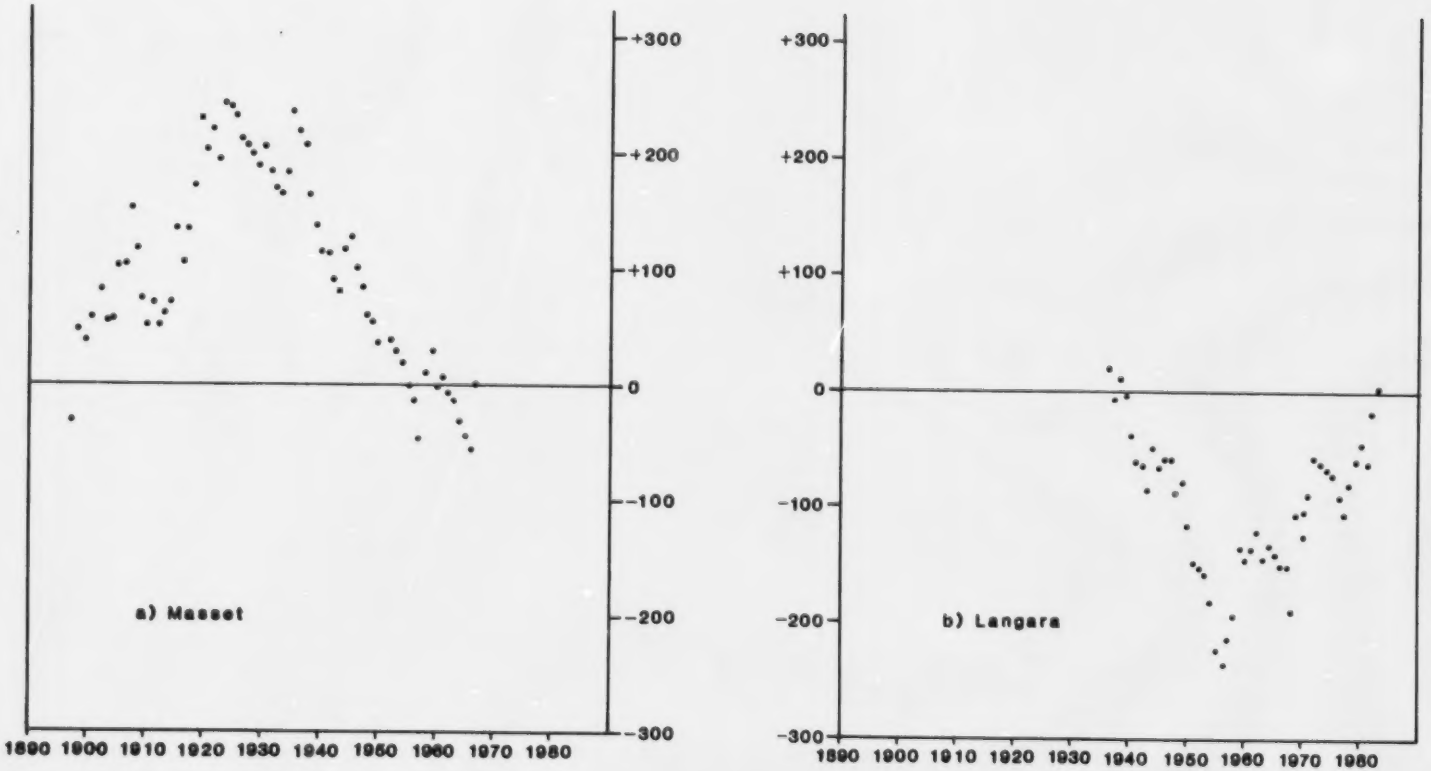

FIGURE 18. Cumulative percent deviation of annual maximum 1-day precipitation at Masset Langara.

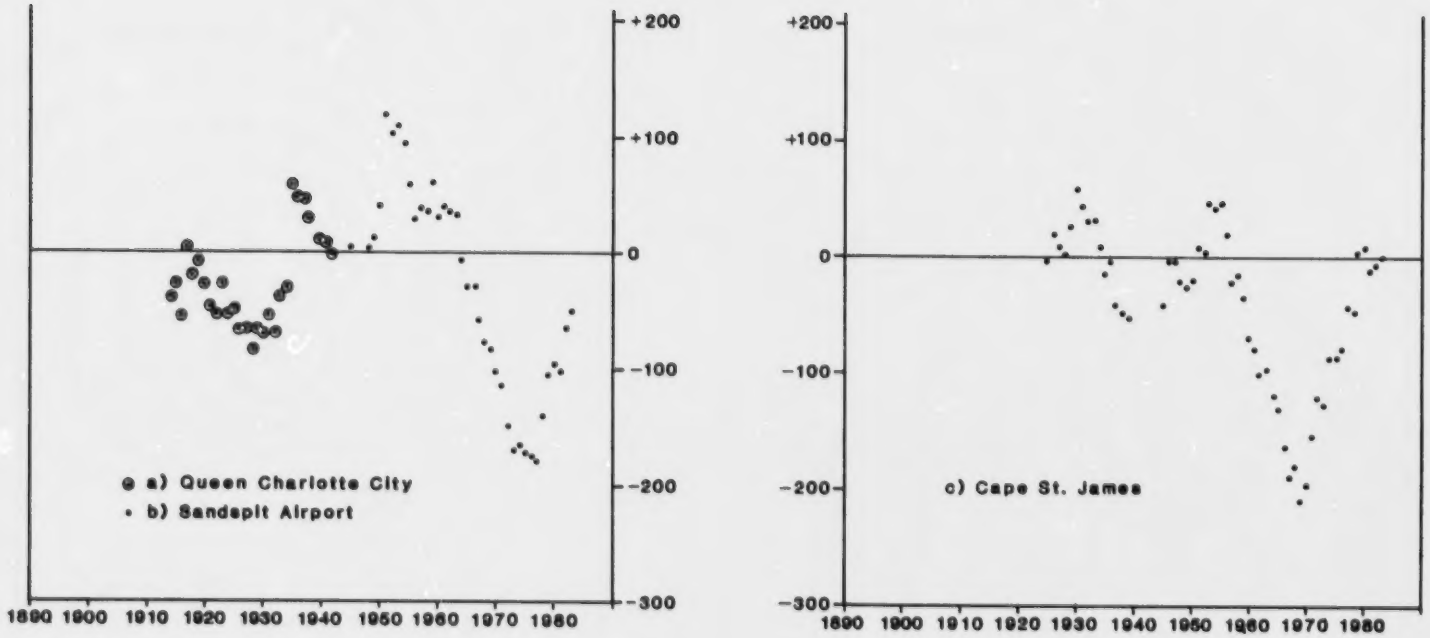

FIGURE 19. Cumulative percent deviation of annual maximum 1-day precipitation at Queen Charlotte City, Sandspit, and Cape St. James.

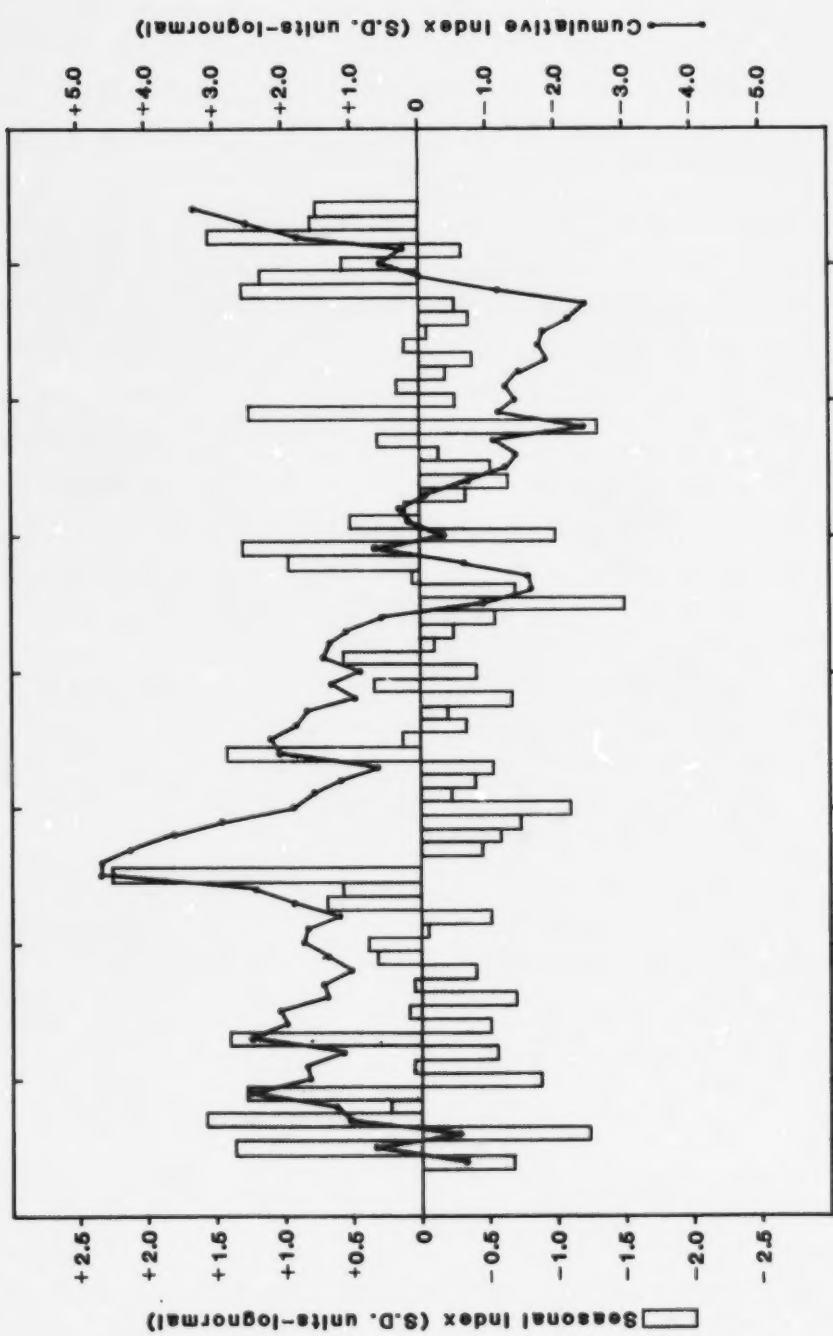

FIGURE 20. October to April seasonal and cumulative index for maxinim 1-day precipitation for central and northern Queen Charlotte Islands.

1923/24, 1933/34 to 1935/36, 1958/59 to 1961/62, these periods have been shorter and/or broken by intervening years of below-normal maxima.

F-tests indicated that the means of annual maximum 1-day precipitation from the years with the highest, middle, and lowest thirds of total October to April precipitation differed significantly at only two of five stations at the 95% level (Table 6).

Frequencies of 1-day precipitation greater than 30 mm were also compared between the years with the highest, middle, and lowest thirds of total October to April precipitation. F-tests indicated that the mean frequencies differed significantly at the 95% level at four out of the five stations (Table 7).

Frequencies of 1-day precipitation greater than 50 mm are concentrated in the periods from 1915/16 to 1923/24, 1933/34 to 1936/37, 1957/58 to 1959/60, and 1978/79 to 1982/83.

TABLE 6. Annual maximum 1-day precipitation in the years with the highest, middle, and lowest thirds of total October to April precipitation

	Mean annual maximum 1-day precipitation (mm)				
Station	Highest third of years	Middle third of years	Lowest third of years	F-test score	Level of significance
Cape St. James	47.3	42.7	36.2	7.79	> 99%
Langara	49.4	47.5	46.6	0.25	< 90%
Masset	47.1	42.5	38.7	2.11	< 90%
Queen Charlotte City	60.9	58.9	49.9	1.21	< 90%
Sandspit Airport	50.8	41.5	41.1	3.64	96%

TABLE 7. Frequencies of 1-day precipitation greater than 30 mm in the years with the highest, middle, and lowest thirds of total October to April precipitation

	Mean annual maximum frequency of days with precipitation greater than 30 mm				
Station	Highest third of years	Middle third of years	Lowest third of years	F-test score	Level of significance
Cape St. James	13.6	10.6	6.1	20.5	> 99%
Langara	5.1	3.7	1.6	10.2	> 99%
Masset	2.9	2.9	1.9	1.90	< 90%
Queen Charlotte City	7.4	7.2	2.8	2.77	92%
Sandspit Airport	4.8	3.7	2.0	7.4	> 99%

4 DISCUSSION

The most striking feature of the climatological data from the Queen Charlotte Islands since 1914/15 is an alternation, with some overlap and short-term fluctuation, between periods having generally above-normal autumn/winter rainfall and temperature, but below-normal snowfall (Type I), and periods having below-normal rainfall and temperature, but above-normal snowfall (Type II). Type I periods occurred from 1923/24 to 1945/46, 1958/59 to 1963/64, and 1974/75 to 1983/84. Type II periods intervened from 1946/47 to 1956/57 and 1964/65 to 1974/75. No overall trend is apparent in the fluctuations.

The climatic fluctuations in the Queen Charlotte Islands appear to be related to persistent changes in atmospheric pressure patterns and gradients over the northern Pacific Ocean and the adjacent Siberian and North American land masses, with associated north-south shifts in the mean position(s) of the autumn/winter storm track(s) across the northeastern Pacific Ocean. Such synoptic-scale changes have been studied by Namias (1969; 1971; 1972a; 1972b; 1978; and 1980) and Namias and Born (1972) for the period from 1947 to 1979. The key occurrences in the synoptic scenario described by Namias are reversals of ocean temperature patterns in the central and eastern North Pacific Ocean and their atmospheric linkages. Namias (1972a) described two quasi-stable ocean temperature patterns:

1. cooler than normal in the north-central Pacific Ocean, combined with warmer than normal in the northeastern Pacific, and
2. the reverse of pattern 1.

Pattern 1 corresponds with warm, generally wet winters in western North America. The locus of the warmest, wettest conditions can shift north and south, depending on the location of the storm track. Pattern 2 corresponds with cool, generally dry winters in western North America. The ocean temperature patterns are linked to climate through changes in the relative strength and position of the semi-permanent Aleutian Low and North Pacific High pressure systems, which in turn affect the position of the storm tracks across the Pacific.

During the period of analysis from 1947 to 1979, pattern 2 (cool, dry western North America) dominated from 1947 to 1958 and was re-established in 1971-72. Pattern 1 (warm, wet western North America) dominated from 1958 to 1971, and was re-established in 1976. The reversals in 1958 and 1976, which resulted in the establishment of pattern 1 ocean temperatures, are both associated with the El Nino phenomenon of the tropical Pacific Ocean. Basically, the El Nino results in the incursion of warm ocean waters into the northeastern Pacific Ocean along the margin of North America. A similar, very strong, incursion occurred during the El Nino of 1982.

The 1947 to 1979 period of Namias' analyses included 2 fluctuations between Type I (warm, wet) and Type II (cool, dry) winter climate regimes in the Queen Charlotte Islands. Winters on the Queen Charlotte Islands since 1946 were classified by their temperature and precipitation indices and compared with the ocean temperature patters identified by Namias (Table 8). Six classes were used in classifying the winters on the Queen Charlotte Islands:

- I: temperature and precipitation indices are both in the highest third of index values since 1914/15.
- i: either the temperature or precipitation index is in the highest third of index values, while the other index is in the middle third of index values since 1914/15.
- 0: both temperature and precipitation indices are in the middle third of index values since 1914/15.
- ii: either the temperature or precipitation index is in the lowest third of index values, while the other index is in the middle third of index values since 1914/15.
- II: temperature and precipitation indices are both in the lowest third of index values since 1914/15.
- III: temperature and precipitation indices are in the opposite highest or lowest third of index values since 1914/15.

TABLE 8. Comparison of winter temperature and precipitation anomalies in the Queen Charlotte Islands with temperature anomaly patterns in the North Pacific Ocean as identified by Namias

Winter	Winter temperture index	Winter precipitation index	One-day maximum ppt. index	Winter climate regime type	Ocean temp. anomaly pattern
1946-47	-0.23	-1.37	-0.34	ii	2
1947-48	-0.09	-0.21	-0.20	0	2
1948-49	-1.28	-0.27	-0.67	ii	2
1949-50	-2.00	-0.78	+0.34	II	2
1950-51	-0.62	-0.63	-0.42	II	2
1951-52	-0.51	+0.23	+0.56	ii	2
1952-53	+0.03	-0.69	-0.10	ii	2
1953-54	-0.47	+0.28	-0.25	III	2
1954-55	+0.01	+0.08	-0.55	0	2
1955-56	-1.59	-0.52	-1.50	II	2
1956-57	-0.68	-1.81	-0.70	II	2
1957-58	+1.30	-0.88	+0.05	III	2
1958-59	+0.22	+0.36	+0.96	i	1
1959-60	+0.66	+2.22	+1.29	I	1
1960-61	+1.31	+0.80	-1.00	I	1
1961-62	+0.14	+0.03	+0.51	0	1
1962-63	+1.19	-0.66	+0.11	III	1
1963-64	+0.52	+0.99	-0.34	I	1
1964-65	-1.08	-1.08	-0.65	II	1
1965-66	-0.46	+0.73	-0.53	III	1
1966-67	-0.06	-0.50	-0.15	ii	1
1967-68	+0.03	-1.02	+0.31	ii	1
1968-69	-2.47	-0.87	-1.30	II	1
1969-70	+0.92	+0.08	+1.24	i	1
1970-71	-1.30	-0.49	-0.27	II	1
1971-72	-1.97	-0.12	+0.16	ii	2
1972-73	-0.37	-0.71	-0.20	ii	?
1973-74	-0.62	-0.08	-0.41	ii	?
1974-75	-0.61	+0.62	+0.10	III	?
1975-76	-0.19	+1.25	-0.05	i	?
1976-77	+1.33	-0.15	-0.37	i	1
1977-78	-0.39	+0.22	-0.26	0	1
1978-79	-0.49	-0.14	+1.30	ii	2?
1979-80	+0.14	+0.79	+1.16	i	?
1980-81	+1.50	+1.65	+0.55	I	?
1981-82	-0.83	-0.08	-0.33	ii	1?
1982-83	+1.69	+0.62	+1.54	I	1?
1983-84	+0.83	+1.00	+0.78	I	1?

Table 8 shows that changes from predominantly Type II (cool, dry) winters to predominantly Type 1 (warm, wet) winters in 1958/59 and 1975/76 correspond to the changes in ocean temperature patterns in the same years noted by Namias. Both changes are associated with the El Nino phenomenon. Another El Nino occurred in 1982, which resulted in two exceptionally strong Type 1 winters in the Queen Charlotte Islands. One the other hand, the Namias hypothesis does not account for the changeover from Type I to Type II winters which occurred in the Queen Charlotte Islands in 1964/65. According to Namias (1972b), this changeover was in the middle of a long period of pattern 1 ocean temperature anomalies which persisted until 1971. On the other hand, precipitation on northern Vancouver Island, which also became above average after 1958/59, remained above average until the mid-1970's, throughout the period suggested by the synoptic model proposed by Namias. The discrepancy between the Namias model and actual precipitation fluctuations on the Queen Charlotte Islands may be a reflection of local variability which is too subtle in scale for a synoptic model that covers the entire north Pacific Ocean and western North America.

Trends in annual runoff volumes on Prince of Wales Island in the southern Alaska Panhandle are similar to precipitation trends in the central and northern Queen Charlotte Islands. On the other hand, neither the Yakoun River runoff data nor the Revillagigedo Island runoff data show an increase since 1975/76. The homogeneity of the Yakoun River data has already been questioned in Section 3.1. The Revillagigedo Island data, however, cannot be rejected on the basis of homogeneity because of the high correlation between the stations. The discrepancy between the Queen Charlotte Island precipitation data and the Revillagigedo Island stream runoff data cannot be resolved from the available information.

The two periods from 1958/59 to 1963/64 and 1974/75 to 1983/84 have had the most consistent clustering of heavy 1-day precipitation events since 1947 at the Queen Charlotte Islands meteorological stations. The period of greater-than-average frequency of 1-day precipitation exceeding 30 mm between 1958 and 1964 was localized to northern Graham Island (Langara and Masset), only briefly affecting Sandspit to the south. Nine of 25 1-day precipitation

amounts exceeding 50 mm occurred during this period at Langara. Above-average frequencies of 1-day precipitation greater than 30 mm have been more widespread throughout the Queen Charlotte Islands since 1974/75. Moreover, one-half of all 1-day precipitation events exceeding 50 mm have occurred during this period at Cape St. James and Sandspit Airport, while seven of 25 such events have occurred at Langara beginning in 1978.

October to April precipitation indices from southern Vancouver Island to the Alaska Panhandle suggest the following synoptic changes are associated with the Type I and II periods identified in the Queen Charlotte Islands.

1. Type I period from 1923/24 to 1945/46 coincides with a period of below-normal precipitation across Vancouver Island and above-normal precipitation across the Alaska Panhandle, indicating a northward shift of the autumn/winter storm track in the northeast Pacific. The Queen Charlotte Islands, in between these two anomalies, show above-normal rainfall, but near-normal precipitation. This period is marked by considerable short-term fluctuation.
2. Type II period from 1946/47 to 1957/58 coincides with a period of above-normal precipitation across southern Vancouver Island and below-normal precipitation from northern Vancouver Island to the Alaska Panhandle, indicating a persistent southerly shift in the autumn/winter storm track.
3. Type I period from 1957/58 to 1963/64 coincides with a period of above-normal precipitation throughout the northeast Pacific area, especially from the central British Columbia mainland coast to the Alaska Panhandle.
4. Type II period from 1964/65 to 1975/76 coincides with a period of above-normal precipitation on Vancouver Island and below-normal precipitation from the Queen Charlotte Islands to the Alaska Panhandle, indicating a persistent southerly shift of the autumn/winter storm track.

5. Type I period from 1975/76 to 1983/84 coincides with a period of fluctuating, but generally below-normal precipitation on Vancouver Island and above-normal precipitation in the Queen Charlotte Islands and the northern Alaska Panhandle, indicating a persistent northerly shift in the autumn/winter storm track.

5 CONCLUSIONS

1. Long-term precipitation data from the Queen Charlotte Islands has low regional coherence, with interstation correlations for October to April precipitation generally less than r=0.7. Thus, trends and fluctuations at any one station may not be applicable in another area of the Queen Charlotte Islands.

2. Most of the long-term Queen Charlotte Islands data sets have changes in homogeneity resulting from changes in station location or instrumentation. Results of single-station trend analyses, such as cumulative percent deviation graphs or n-year moving means must be interpreted cautiously with respect to climatic trends or fluctuations.

3. Queen Charlotte Islands climate data show an alternation between periods of above-normal autumn/winter rainfall and temperature, but below-normal snowfall (Type I); and periods with below-normal autumn/winter rainfall and temperature, but above-normal snowfall (Type II). These fluctuations apparently result from persistent shifts in the mean position of the autumn/winter stormtrack across the northeastern Pacific. Type I periods occurred from 1923/24 to 1945/46, 1957/58 to 1963/64, and 1974/75 to 1983/84. Type II periods intervened from 1946/47 to 1956/57 and 1964/65 to 1973/74.

4. The above-normal precipitation in the Queen Charlotte Islands since 1976/77 is not reflected in runoff data from the Yakoun River or on Revillagigedo Island. Runoff trends in Old Tom Creek on Prince of Wales Island, on the other hand, show a similar trend to Queen Charlotte Islands precipitation.

5. The most likely periods during which stream channel enlargement occurred on the Queen Charlotte Islands because of above-normal precipitation and runoff are: 1938-1946, 1958-1964, and 1975-1984.

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APPENDIX 1

Exceedance Frequencies of Daily Total Precipitation

(Sample page of computer printout)

PROGRAM: GRP211
RUN DATE: 02/06/85

ELEMENT #010 - TOTAL RAINFALL (MM)
TOTAL RAINFALL
ABSOLUTE FREQUENCY

1058003 TASU SOUND

1982

RANGE	CLASS	TOTAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0300.0 - 0999.9	01	0	0	0	0	0	0	0	0	0	0	0	0	0
0250.0 - 0999.9	02	0	0	0	0	0	0	0	0	0	0	0	0	0
0200.0 - 0999.9	03	0	0	0	0	0	0	0	0	0	0	0	0	0
0150.0 - 0999.9	04	0	0	0	0	0	0	0	0	0	0	0	0	0
0100.0 - 0999.9	05	0	0	0	0	0	0	0	0	0	0	0	0	0
0090.0 - 0999.9	06	1	0	0	0	0	0	0	0	0	0	1	0	0
0080.0 - 0999.9	07	2	1	0	0	0	0	0	0	0	0	1	0	0
0070.0 - 0999.9	08	3	1	0	0	0	0	0	0	0	0	1	0	0
0060.0 - 0999.9	09	9	3	0	0	1	0	0	0	0	0	1	0	0
0050.0 - 0999.9	10	12	3	0	0	3	0	0	0	0	0	2	0	0
0040.0 - 0999.9	11	18	3	1	0	4	1	0	0	0	0	2	1	0
0030.0 - 0999.9	12	29	5	1	1	5	1	0	0	0	0	3	1	2
0020.0 - 0999.9	13	45	5	1	5	6	3	0	2	0	0	4	4	2
0010.0 - 0999.9	14	77	6	5	8	8	6	0	2	1	3	6	4	4
0000.1 - 0999.9	15	171	13	13	18	14	10	0	3	4	3	8	7	9
	TOTAL	171	13	13	18	23	21	5	11	13	11	15	14	14
	VALID REPORTS	346	27	26	31	30	31	30	28	31	29	28	28	27

1058003 TASU SOUND

1983

RANGE	CLASS	TOTAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0300.0 - 0999.9	01	0	0	0	0	0	0	0	0	0	0	0	0	0
0250.0 - 0999.9	02	0	0	0	0	0	0	0	0	0	0	0	0	0
0200.0 - 0999.9	03	0	0	0	0	0	0	0	0	0	0	0	0	0
0150.0 - 0999.9	04	0	0	0	0	0	0	0	0	0	0	0	0	0
0100.0 - 0999.9	05	0	0	0	0	0	0	0	0	0	0	0	0	0
0090.0 - 0999.9	06	3	0	0	0	0	0	1	0	0	0	2	0	0
0080.0 - 0999.9	07	4	1	0	0	0	0	1	0	0	0	2	0	0
0070.0 - 0999.9	08	7	2	0	0	0	0	1	0	0	0	2	0	0
0060.0 - 0999.9	09	11	5	1	0	0	0	1	0	0	0	2	0	1
0050.0 - 0999.9	10	17	6	1	0	0	0	1	0	0	0	2	0	1
0040.0 - 0999.9	11	21	6	2	0	0	0	1	0	0	0	2	0	1
0030.0 - 0999.9	12	33	7	3	0	1	1	2	0	0	0	3	0	1
0020.0 - 0999.9	13	47	9	5	2	2	2	4	0	1	0	6	0	1
0010.0 - 0999.9	14	84	15	10	7	5	4	6	2	6	2	6	1	1
0000.1 - 0999.9	15	175	18	12	13	13	14	13	13	19	11	14	13	15
	TOTAL	175	18	12	13	13	14	13	13	19	11	14	13	15
	VALID REPORTS	331	27	24	29	29	30	26	27	29	29	27	29	29

APPENDIX 2

Detailed Histories of Queen Charlotte Islands Climate Stations

1. Masset

   - station opened June 1897.
   - many short gaps in early record to 1901, again in 1904 and 1910.
   - possible location change in 1909.
   - definite location change by 1913; station now reported at an elevation of 3 m instead of the previous 9 m. The evidence suggests the change actually occurred in 1909, when the observer is known to have changed his residence to a location lower in elevation.
   - first observer retires in 1919; coincides with a suspected change in station homogeneity.
   - station closed October 1951 to March 1952; may have reopened in a different location.
   - station closed in March 1968.
   - station reopened in November 1971 as Masset CFS (Canadian Forces Station), 4' longitude (5 km) further east.
   - precipitation data become erratic after 1976.
   - station closed in February 1981.
   - station reopened in September 1981 as Masset Tow Hill, a further 6' longitude (7 km) further east.

2. Langara Lighthouse

   - station opened in July 1936.
   - Nipher-shielded snow gauge installed in 1965.

3. Sandspit Airport

   - station opened in September 1945.
   - station closed in March 1946.
   - station reopened in August 1948.
   - Nipher-shielded snow gauge installed in 1966.

4. Queen Charlotte City

   - station opened in October 1914.
   - no snowfall recorded from 1931 to 1937. Winter precipitation should be reduced from 80 to 160 mm less than expected during this period.
   - station closed in October 1939.
   - station reopened at or near old location in April 1940.
   - station was moved in 1943, to a location about 3 km further west. Since this is a high gradient rainfall area, the new station location was much wetter.
   - station closed in December 1948.

5. Tlell

   - station opened in January 1950.
   - station location changed in June 1959, to 1' longitude (1.5 km) further east.
   - station location changed in November 1966, to about 4' latitude (6 km) further south.
   - station location changed in November 1971, to a further 2' latitude (3 km) further south.
   - Bob Marsh (B.C. Ministry of Environment) reports the rain gauge to have been in too small a clearing, in fact, under a tree.

6. Dead Tree Point

   - station opened in February 1939.
   - station closed in January 1958.

7. Tasu Sound

   - station opened in January 1963.
   - location changed in August 1966.

8. Cape St. James Lighthouse

- station opened in August 1925.
- many short data gaps in winter months from 1925 to 1940.
- station closed in April 1940.
- station reopened in December 1944.
- Nipher-shielded snow gauge installed in 1964.

APPENDIX 3

Winter Precipitation (October to April) Indices

for Long-Term Queen Charlotte Islands Stations

STATION INDICES

WINTER	MASSET	QUEEN CHARLOTTE CITY	LANGARA	DEAD TREE POINT	SANDSPIT	TASU SOUND	MEAN INDEX	CUMULATIVE INDEX
1914-15	- .05	- 1.55					- .80	- .80
1915-16	+ 1.84	+ .67					+ 1.26	+ .46
1916-17	- .78	- 1.08					- .93	- .47
1917-18	+ 3.16	+ 2.41					+ 2.79	+ 2.32
1918-19	+ .80	- .34					+ .23	+ 2.55
1919-20	- 1.77	- 2.02					- 1.90	+ .65
1920-21	- .64	- .08					- .36	+ .29
1921-22	- .60	- .56					- .58	- .29
1922-23	- .50	+ .25					- .13	- .42
1923-24	+ 1.21	+ 1.73					+ 1.47	+ 1.05
1924-25	+ .10	+ .07					+ .09	+ 1.14
1925-26	- .37	+ 1.06					+ .35	+ 1.49
1926-27	+ .30	+ .52					+ .41	+ 1.90
1927-28	- .75	- .60					- .68	+ 1.22
1928-29	- .04	- .86					- .45	+ .77
1929-30	- .73	- .51					- .62	+ .15
1930-31	+ 1.22	+ 1.50					+ 1.36	+ 1.51
1931-32	+ .71	+ .28					+ .50	+ 2.01
1932-33	- 1.12	- .04					- .58	+ 1.43
1933-34	- .42	+ .24					- .09	+ 1.34
1934-35	+ .10	- .64					- .27	+ 1.07
1935-36	- .87	+ .28					- .30	+ .77
1936-37	- .72	- .57	- .24				- .51	+ .26
1937-38	- .33	+ .42	- .20				- .04	+ .22
1938-39	+ .32	+ .37	+ 1.11				+ .60	+ .82
1939-40	+ 1.38	M	+ .09	+ 1.74			+ 1.07	+ 1.89
1940-41	- 1.22	- 1.48	- 1.07	- .15			- .98	+ .91
1941-42	+ .83	+ .96	+ .76	+ 1.20			+ .94	+ 1.85
1942-43	- .66	- .44	+ .48	- .05			- .17	+ 1.68
1943-44	+ .34		- .06	- .62			- .11	+ 1.57
1944-45	+ .28		+ .52	- .61			+ .06	+ 1.63
1945-46	+ .58		- .24	- .14	+ .42		+ .16	+ 1.79
1946-47	- 1.84		- .57	- 1.71	M		- 1.37	+ .42
1947-48	- .87		+ .37	- .14	M		- .21	+ .21
1948-49	- .44		- .41	+ .59	- .83		- .27	- .06
1949-50	- .11		- 1.77	- .73	- .49		- .78	- .84

STATION INDICES

WINTER	MASSET	QUEEN CHARLOTTE CITY	LANGARA	DEAD TREE POINT	SANDSPIT	TASU SOUND	MEAN INDEX	CUMULATIVE INDEX
1950-51	- 1.20		- .82	- .41	- .09		- .63	- 1.47
1951-52	M		- .02	+ .91	- .21		+ .23	- 1.24
1952-53	- .85		- 1.86	+ .12	- .18		- .69	- 1.93
1953-54	- .13		- .72	+ 1.63	+ .34		+ .28	- 1.65
1954-55	- .28		+ .36	+ .71	- .47		+ .08	- 1.57
1955-56	- .75		- 1.71	+ .50	- .13		- .52	- 2.09
1956-57	- 1.85		- 1.59	- 1.91	- 1.90		- 1.81	- 3.90
1957-58	- .80		- 1.31	- .94	- .46		- .88	- 4.78
1958-59	+ .29		+ .29		+ .49		+ .36	- 4.42
1959-60	+ 2.71		+ 2.24		+ 1.71		+ 2.22	- 2.20
1960-61	+ .78		+ .90		+ .73		+ .80	- 1.40
1961-62	- .05		+ .95		- .81		+ .03	- 1.37
1962-63	- .74		- .36		- .88		- .66	- 2.03
1963-64	+ .13		+ 1.15		+ .47	+ 2.22	+ .99	- 1.04
1964-65	- .90		- .96		- 1.62	- .84	- 1.08	- 2.12
1965-66	+ 1.43		+ .18		+ .77	+ .53	+ .73	- 1.39
1966-67	- .13		- .18		-	- 1.68	- .50	- 1.89
1967-68	- .10		- .76		- 1.79	- 1.41	- 1.02	- 2.91
1968-69	M		- 1.71		- .71	- .19	- .87	- 3.78
1969-70	M		- .12		- .55	+ .92	+ .08	- 3.70
1970-71	M		- 1.02		- .12	- .34	- .49	- 4.19
1971-72	- .57		+ .28		+ .33	- .50	- .12	- 4.31
1972-73	- .97		- .44		- .87	- .57	- .71	- 5.02
1973-74	+ .82		+ .32		- .67	- .80	- .08	- 5.10
1974-75	+ .13		+ .73		+ .63	+ .98	+ .62	- 4.48
1975-76	+ 1.19		+ 1.30		+ 1.63	+ .89	+ 1.25	- 3.23
1976-77	- 1.07		+ .05		+ .10	+ .31	- .15	- 3.38
1977-78	+ .57		+ .36		+ .29	- .36	+ .22	- 3.16
1978-79	- .60		+ 1.50		- .78	- .66	- .14	- 3.30
1979-80	+ .49		+ 2.00		+ .51	+ .15	+ .79	- 2.51
1980-81	+ .69		+ 1.94		+ 2.03	+ 1.93	+ 1.65	- .86
1981-82	+ .42		+ .85		- .74	- .84	- .08	- .94
1982-83	+ 1.30		+ .02		+ 1.28	- .12	+ .62	- .32
1983-84	+ 1.73		- .65		+ 2.53	+ .38	+ 1.00	+ .68